Technical Report 789

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Validation of the Realistic Air Defense Engagement System (RADES)

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U. S. Army
Research Institute for the Behavioral and Social Sciences

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Science Applications International Corporation

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This report describes the Realistic Air Defense Engagement System (RADES) and research performed to assess its validity. RADES is an air defense simulator consisting of subscale aircraft, an aircraft position/location system, air defense weapon systems, and an electronic interface that connects the weapon to a data collection and communication system. Short Range Air Defense (SHORAD) crews are brought to the RADES range; the weapon is connected to the interface, and the crew is given an operations order, alerted, and cued to the azimuth of the incoming aircraft. Data are automatically collected from the weapon and crew while they engage the RADES aircraft. Data were collected from four Chaparral crews and six Stinger teams during the spring of 1984. Data included times and ranges for critical engagement events, as well as aircraft identification accuracies and kill or miss data. Data from these tests were analyzed and compared both to theoretical predictions derived from a computer model that took as input known physical limitations of weapons, human reaction times, and the flight path of the aircraft and to performance data obtained (Continued)

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19. Abstract (Continued)

in earlier full-scale studies reported in the air defense literature. In both cases the data obtained from RADES were consistent with the criteria established for empirical validity. Keywords: Forward Area Air Defense, Air defense, Short range (Distance). (SDW) Chaparral missiles, Stinger missiles, Surface to air missiles,

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Human Factors in Training and
Operational Effectiveness

FOREWORD

The Weapon Systems Design Team of the Fort Bliss Field Unit of the Army Research Institute for the Behavioral and Social Sciences (ARI) performs research and development in human performance integration relating to Army air defense. In the past, research concerning Forward Area Air Defense (FAAD) has been limited by the lack of a dedicated testing facility. In response to this need, the Fort Bliss field unit has overseen the design, development, and subsequent validation of such a testbed. This Realistic Air Defense Engagement System (RADES) employs actual FAAD weapon systems and crews to engage subscale hostile and friendly aircraft in an outdoor, desert environment. This report describes RADES and the initial validating research.

This research was performed in partial fulfillment of the Fort Bliss Field Unit's mission to fabricate and test a simulation facility for the evaluation of SHORAD/MANPAD air defense weapon system personnel. The research was authorized by a joint study concept memorandum between ARI and the U.S. Army Air Defense Artillery School (USAADASCH) entitled, "Portable SHORAD/MANPAD Facility for Simulation, Training, and Evaluation," dated 9 November 1981. Results and lessons learned from this research were briefed to USAADASCH in FY85.

Edgar M Johnson

EDGAR M. JOHNSON
Technical Director

VALIDATION OF THE REALISTIC AIR DEFENSE ENGAGEMENT SYSTEM (RADES)

EXECUTIVE SUMMARY

Requirement:

To develop and validate a Forward Area Air Defense (FAAD) testbed to investigate doctrinal and human factors issues in air defense.

Procedure:

The Realistic Air Defense Engagement System (RADES) is an air defense simulator consisting of subscale aircraft, an aircraft position/location system, actual air defense weapon systems, and an electronic interface that connects the weapon to a sophisticated data collection and communication system. FAAD crews are brought to the RADES minirange, and the weapon is connected to the interface. The crew is given an operations order, alerted, and cued to the azimuth of the incoming aircraft. Data are automatically collected from the weapon and crew while they engage the RADES aircraft.

In this experiment, data were collected from four Chaparral crews and six Stinger teams during the spring of 1984. Data included times and ranges for critical engagement events, as well as aircraft identification accuracies and kill or miss data. Data from these tests were analyzed and compared both to theoretical predictions derived from a computer model that took as input known limitations of weapons, human reaction times, and the flight path of the aircraft and to performance data from earlier, full-scale studies reported in the air defense literature.

Findings:

Data obtained from RADES were consistent with the criteria established for empirical validity. It is concluded that RADES is a representative FAAD simulation system.

Utilization of Findings:

To date, RADES has provided the air defense community with (1) low-cost, accurate analyses of air defense performance and the effectiveness of potential system modification; (2) realistic air defense training; and (3) manpower, personnel, and

training data to ensure that future air defense systems effectively employ human operators and crews. Examples include (1) the use of RADES target systems to support SGT York collective and live-fire training during FY85; (2) the use of RADES target systems to support Vulcan live-fire training and annual service practice during FY85 and FY86; (3) the use of the RADES testbed to evaluate the Tripod Mounted Stinger concept in October 1985; (4) the use of information derived from RADES to provide a detailed manpower, personnel, and training analysis of the Tripod Mounted Stinger concept in October 1985; (5) the use of the RADES testbed for evaluation and training of the Pedestal Mounted Stinger candidate selection platoon in September 1986; and (6) the use of the RADES vision laboratory for testing, selection, and group assignment of both Pedestal Mounted Stinger and Line of Sight-Forward candidate selection crewmen in FY86 and FY87.

Further development and use of this testbed will lead to recommendations for air defense systems, hardware, procedural modifications, and a realistic, collective, fire-unit trainer/evaluator.

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THE PROBLEM

The Military Problem

The military problem driving the present research is to simulate, measure, parameterize, and improve the engagement performance of Short Range Air Defense (SHORAD) crews.

Over the past twenty years, researchers have struggled to find an accurate means of measuring SHORAD ground-to-air engagement efficiency and effectiveness. During that period, military researchers and evaluators have evolved efficiency measures into part-task event times and ranges, and effectiveness measures into percentages of correct aircraft identifications, threat kills credited, and friendly aircraft fratricides debited. However, the complexity and diversity of weapon systems, aircraft, and munition types, and the state-of-knowledge concerning the perceptual and cognitive responses of the SHORAD crewman have had a profound effect on the investigations conducted by these researchers. Investigators have been forced to employ part-task measurement, and then extrapolate to the whole-task combat environment. As a result of these fragmented probes into SHORAD processes and products, both the part-task and whole-task parameter estimates have become increasingly obscure.

Increasing lethality, range, numbers of weapon systems, computer-driven simulation requirements, and a desire to know the capabilities and limitations of the SHORAD soldier have aroused considerable attention to the problem of SHORAD engagement measurement over the last decade. In the last five years, the ARI Field Unit at Fort Bliss, Texas, in cooperation with the US Army Air Defense Artillery School (USAADASCH) at Fort Bliss, explored manned simulators, computer models, and subscale target engagement simulation facilities as candidate solutions to the SHORAD measurement and evaluation need.

Electing the subscale engagement simulation alternative, ARI commissioned Science Applications International Corporation (SAIC) in the development of a Realistic Air Defense Engagement System (RADES). In March, April, and May of 1984, ARI and SAIC conducted tests of the Stinger and I-Chaparral weapon systems using the new mini-range facility located at White Sands Missile Range, New Mexico. The purposes of these tests were to validate RADES efficiency and effectiveness measures and to provide population-representative parameter estimates of part-task crew behaviors under realistic whole-task engagement conditions.

The Research Problem

The present investigation was undertaken to assess the validity of RADES as a testbed for the measurement of Forward Area Air Defense (FAAD) unit performance. RADES-acquired part-task and whole-task efficiency and effectiveness data were compared against results taken from prior full-scale experiments and calculated tolerance limits obtained from a simulation model. Specific engagement efficiency measures evaluated were time and range of: visual aircraft detection, identification friend or foe interrogation, visual aircraft identification, lock-on, superelevation, and fire. Effectiveness measures assessed were percent of correct visual aircraft identifications, threat aircraft kills, and friendly aircraft fratricides.

BRIEF SYSTEM SUMMARY

The Realistic Air Defense Engagement System (RADES) is a prototype air defense engagement simulation that does not employ live fire. RADES exploits state-of-the-art technology to simulate and measure the essential engagement activities of Forward Area Air Defense (FAAD) crews and teams who use actual Short Range Air Defense (SHORAD) weapon systems in a quasi-realistic range environment. Each weapon system is electronically interfaced to the integrated RADES data collection and control system. RADES monitors and records the location of each weapon system, where it is pointing (azimuth and elevation), and what state it is in (e.g., "lock-on", "fire", "interrogate", etc.). RADES also monitors and records all voice communications over the fire unit's tactical intercom, thereby collecting key verbal data during the engagement sequences (e.g., "detection" and "identification"). RADES targets are scale-modeled, fixed and rotary wing aircraft of U.S. and Soviet design. A position/location system provides realtime tracking of these targets to within plus or minus eight feet. Thus, by knowing the location of the targets, the location of the weapon system, the state of the weapon, the direction the weapon is pointing, and the crew communications, RADES can simulate the FAAD engagement environment and measure the performance of the crews and teams.

SYSTEM DESCRIPTION

The Realistic Air Defense Engagement System is designed for instrumented field exercise data acquisition. RADES measures air defense weapon system and collective crew, part-task, engagement behaviors in a representative, whole-task, engagement environment. Stimuli used in RADES are subscale fixed and rotary wing aircraft presented to a crew or team in a scaled airspace.

Weapons systems which may be studied, tested, or trained using RADES include:

1. The basic Chaparral missile system.
2. The Improved Chaparral missile system.
3. The Self-Propelled Vulcan 20mm gun system.
4. The Redeye man-portable missile system.
5. The Stinger man-portable missile system.
6. The Roland missile system.
7. The Product Improved Vulcan Air Defense (PIVAD) gun system.

The Roland and PIVAD systems have not yet been fully integrated into RADES due to low availability.

RADES uses two vans for its data acquisition center and a third van for maintenance support. The Core Instrumentation Subsystem van contains RADES computers, interfaces, and peripherals. The Mission Control Van contains displays, aircraft control equipment, and communication equipment. The third van contains spare parts, work benches, supplies, tools, and test equipment. RADES also includes a multi-user data analysis, software support, and an intermediate repair facility at Science Applications International Corporation, El Paso, Texas. Equipment manufacturers and their representatives provide depot maintenance.

RADES's current test site is Condron Field, White Sands Missile Range, New Mexico. The test range is a 2,000 meter by 2,000 meter square area under the control of the White Sands Range Control Directorate, at the White Sands base complex. RADES operations at Condron Field are limited to engagement simulation operations, since Condron Field is not a live fire test range.

RADES Architecture

RADES has three major subsystems: The Range Data Measurement Subsystem, the Range Monitoring and Communication Subsystem, and the Core Insrumentation Subsystem (see Figure 1). The Range Data Measurement Subsystem contains all functions relating to target control, navigation, and guidance including engagement (kill) signature effects release. The Range Monitoring and Communications Subsystem incorporates all functions associated with weapon system engagement event sensing, tactical voice communications, audio tape sound effects generation, and test control voice communications. The Core Instrumentation Subsystem provides scenario generation, test background file definition and initialization, data base management, interactive test and calibration, realtime engagement data acquisition, post-processing, and statistical data analysis.

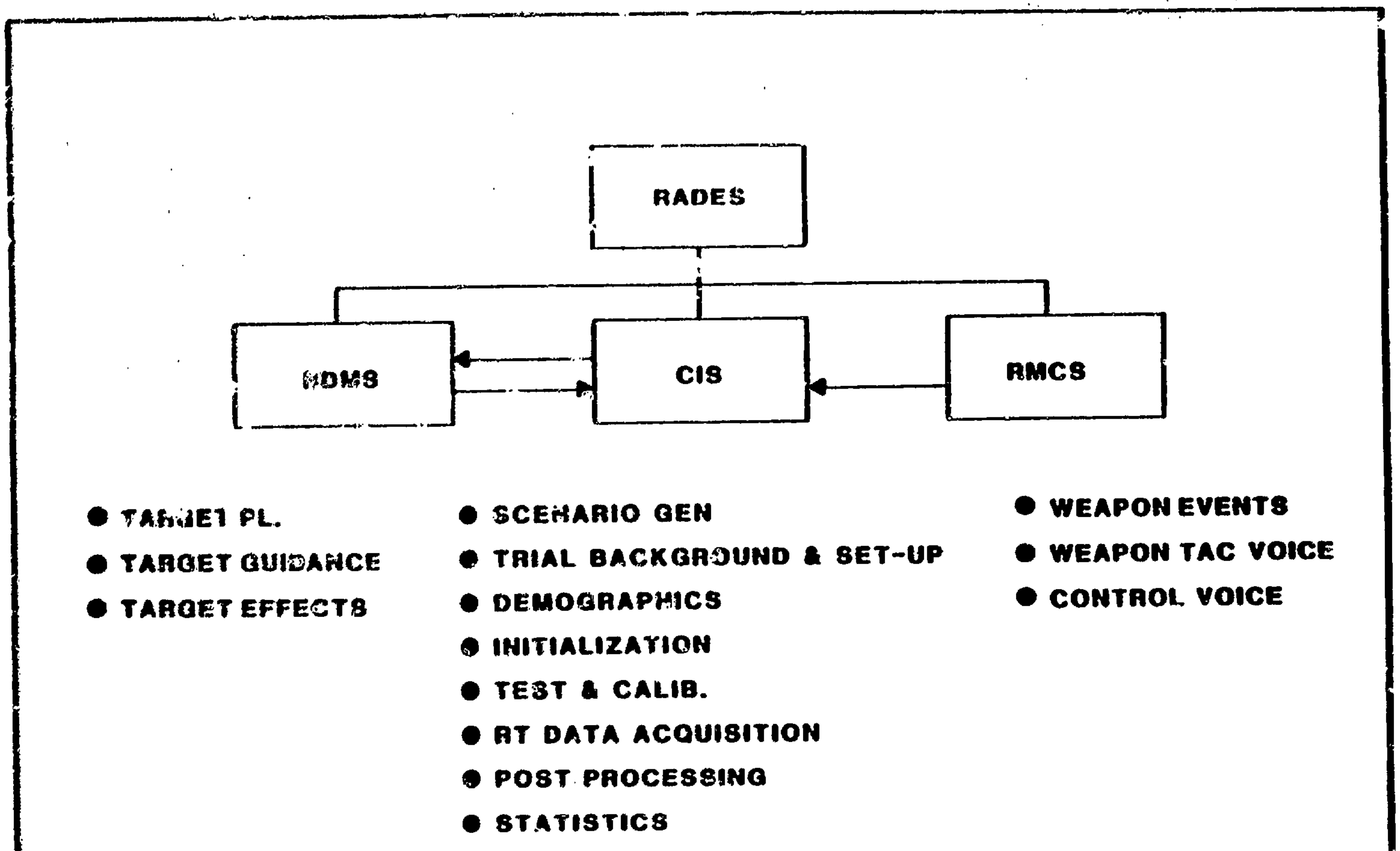


FIGURE 1. RADES DESIGN CONCEPT

The Range Data Measurement Subsystem (RDMS)

The Range Data Measurement Subsystem contains two target types: flying fixed wing aircraft and stand-mounted rotary wing aircraft. Both types include representatives of hostile as well as friendly aircraft. Flying fixed wing models are radio controlled, 1:7 scale, fiberglass targets; friendly targets are U.S. F-16s, and hostile target types are Soviet MIG-27s. Human pilots control target flight with radio control transmitters. A graphics display of the intended and achieved airspeed, location, and altitude of the aircraft is monitored by an air traffic controller, who guides the pilots through each flight. Each pixel on the display represents approximately 30 feet, in an aerial view of the miniature range.

Flying targets are launched by conventional runway take-offs, requiring about 600 feet of runway, or by a pneumatic launcher, requiring about 75 feet of forward area. Safety requires engines to be started by using an electric starter motor applied manually to a cone on the front of the engine. Each aircraft carries enough fuel for 20 minutes of flight. Payload also includes a scaled infrared signal generator, a kill indicator, a tracking transponder device, transponder battery pack, a radio receiver, and coupled, servo-control mechanisms. Throttle, ailerons, and elevators constitute the target control surfaces manipulated by the pilot. Flying targets are stabilized by miniature rate-gyros which maintain "pitch" and "yaw" axes between pilot radio control commands.

Radar reflective tape, applied to the leading edge of the target wings, provides radar returns required by acquisition and track, radar-equipped weapon systems. Flying targets land on the Condron Field runway in a controlled skid for recovery. Originally, fixed landing wheels were used but were found to contradict the scaled profile of the aircraft and were therefore removed.

Flying targets are interrogated by radio signal every 200 milliseconds to establish their coordinate location, compute their airspeed, and assess weapon-to-target engagement effects. Figure 2 depicts the three ground stations used to triangulate the location of the aircraft's on-board transponder in an interrogation sequence for a single target. The master ground station returns three time-of-arrival (TOA) messages to the CIS-contained RADES main computer system for each interrogation sequence, as shown in Figure 3. The CIS mini-computer calculates the position of the flying target and passes it to a graphics display processor for display updating. Computed location of the target is accurate to within 16 feet of the absolute target location (i.e., + or - 8 feet in each axis).

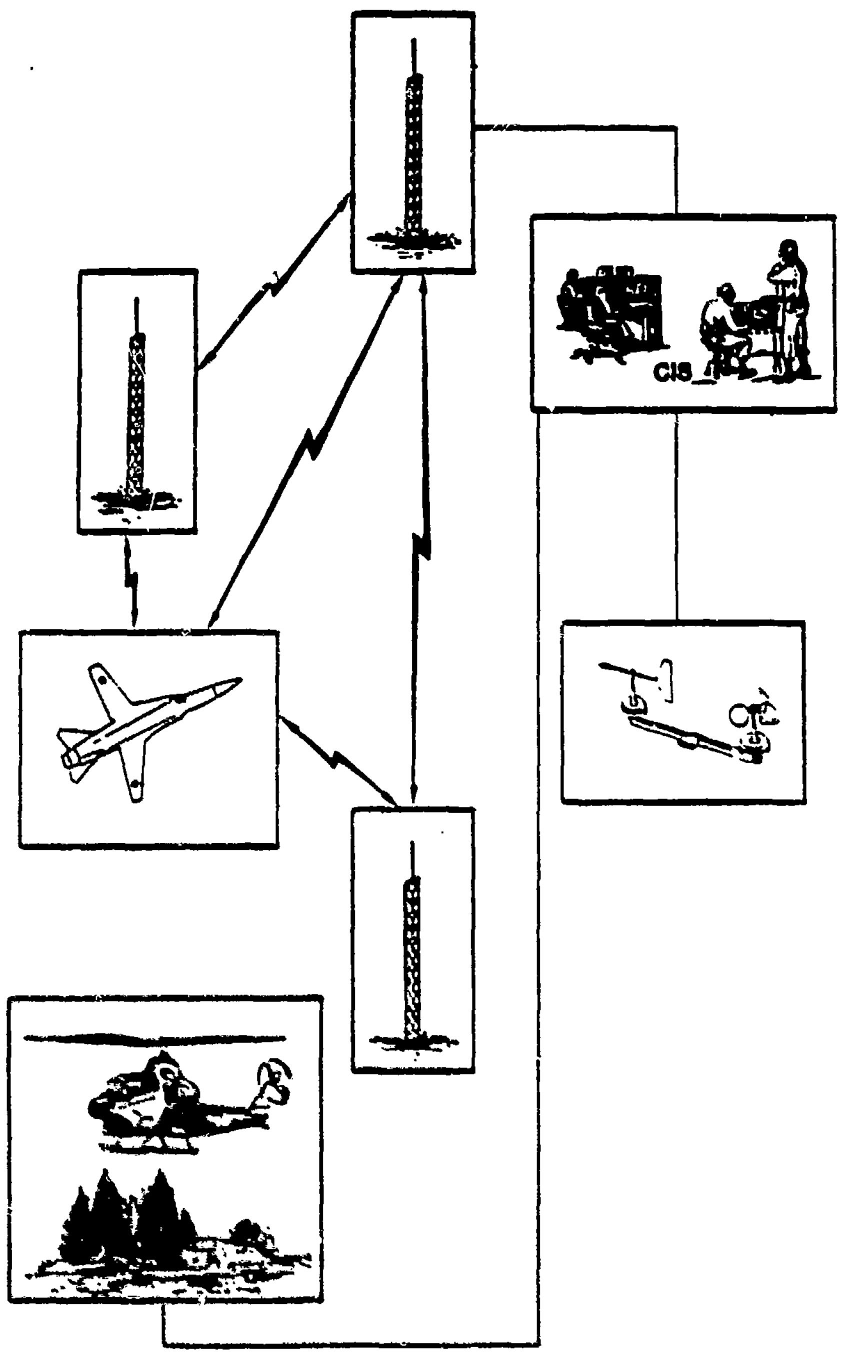


FIGURE 2. RANGE DATA MEASUREMENT SUBSYSTEM

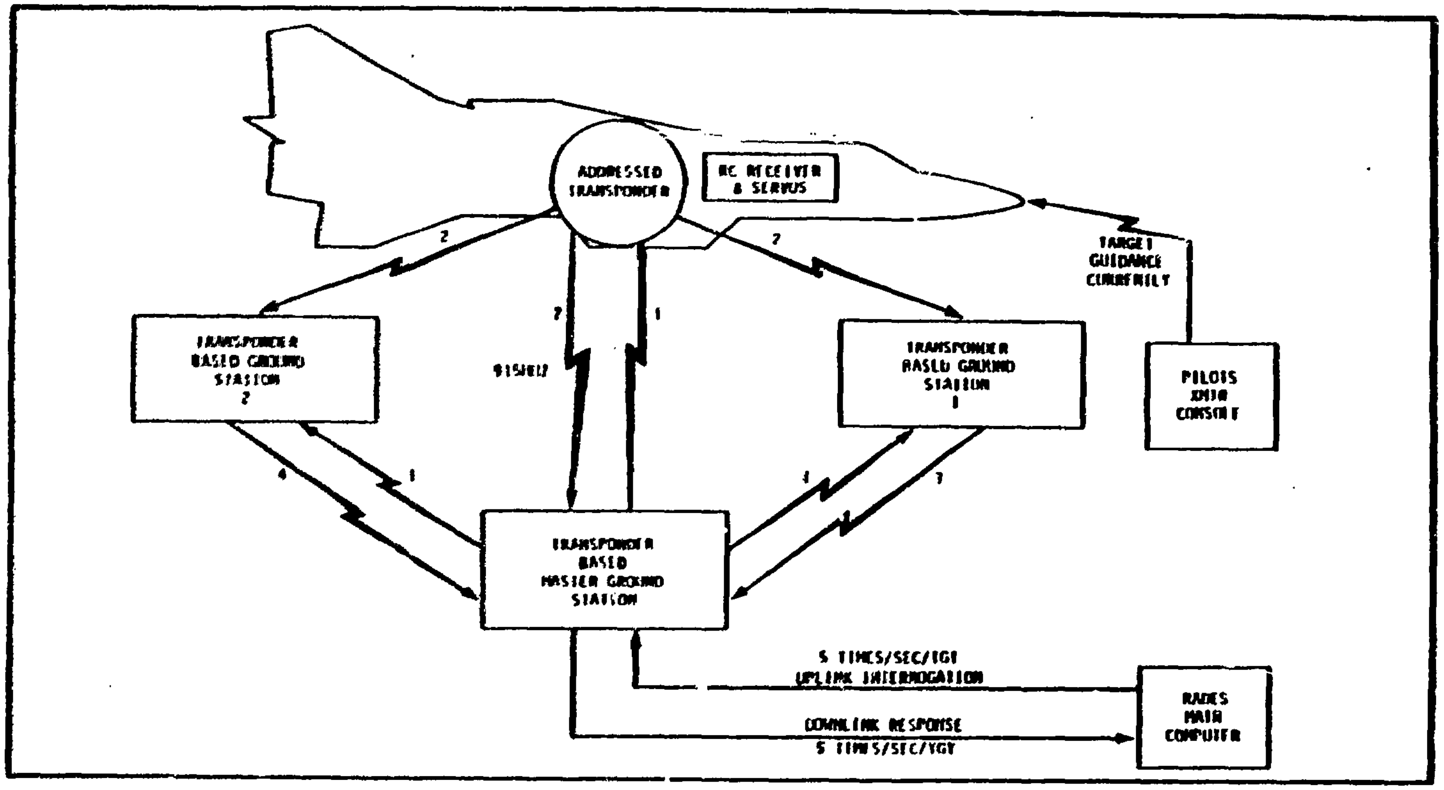


FIGURE 3. RADES RDMS FLYING AIRCRAFT TRACKING AND CONTROL SEQUENCE

The second type of target is the stand-mounted rotary wing target. Each stand holds a single, 1:5 scale, fiberglass target shell equipped with a kill generator and an infrared source. Friendly targets are U.S. Cobra models and hostile targets are Soviet Hind-D models. The stand is equipped with lift devices to raise, lower, and rotate the targets and is deployed down range, in defilade to the weapon system. Radar reflective tape is applied to the motorized rotor blades providing the radar returns needed by radar-equipped weapon systems.

Helicopter targets may be presented simultaneously with fixed wing targets. Since location of the helicopter stands is fixed, the position is manually initialized before the start of test. Time of helicopter stand raise and lower is pre-determined according to scenario, as is the helicopter heading.

Underground cables provide the stands with command signals and power. The CIS computer system commands the lift devices, in accordance with instructions input by the scenario initializer. The targets can also be operated from a control panel for system test and calibration.

Besides the targets and target controlling equipment, the RDMS includes a remote weather station, hard-wired to a digital weather computer. Barometric pressure, wind velocity, wind direction, and temperature are displayed by the digital weather computer on a display panel in the Mission Control Van. Weather data are manually initialized at the start of each trial. Weather sensors are externally mounted to the vans to capture weather information for the miniature range area. Currently, this station is used only to sense and report weather conditions on the range which may adversely affect performance of RADES aircraft.

<u>Range Monitoring and Communications Subsystem (RMCS)</u>

The function of the RMCS is to capture:

1. Critical engagement event data.
2. Tactical voice communications.
3. Weapon azimuth and elevation.
4. Search radar activation.
5. Search radar detection.
6. Visual aircraft detection.
7. Identification friend or foe (IFF) interrogation.
8. Acquisition, track and lock-on.
9. Fire and reattack.
10. Post launch missile arm.
11. Break-off of engagement from the exercising weapon system.

Since each weapon affords a unique subset of these events, the RMCS provides unique cabling peculiar to each selected weapon system. These weapon circuit taps are depicted in Figures 4, 5, 6, and 7.

A cable, extending from the weapon, connects to a universal (interface) junction box. The junction box serves as a signal conditioning station, which adjusts to the peculiar inputs of each weapon, releases local audio and visual effects on the weapon, and prepares the signals captured for transmission to the CIS van. In addition, the junction box simulates all the signals captured from each of the weapon systems for purposes of system test and calibration. The junction box is located with the weapon system approximately 1,000 feet from the RADES vans.

Signals captured from the weapon system are transmitted by underground cable to a microprocessor located in the CIS van. Within the chassis of this microprocessor, signal preparation cards receive and hold the signals transmitted from the universal junction box. Once every 200 milliseconds, the microprocessor reads the signals and writes these data to the main CIS minicomputer.

The microprocessor converts analog signals to digital form (e.g., for azimuth, elevation, and voice signals), filters noise and spikes from the tactical voice communications, holds discrete event signals to prevent data loss, and passes the data to the CIS main computer. The microprocessor is a component assembly in the CIS and is the main interface between the CIS and the RMCS.

Cabled to the universal junction box is a time-codable voice recorder. The four channel cassette recorder is in the CIS van and records all tactical voice messages on standard cassette recording tape. Each voice message is time-encoded and may be rapidly accessed using the digital time code.

The RMCS also contains an administrative communications system. The system serves communications between the vans and deployed pilot and maintenance personnel. This administrative communication system consists of a base station radio and four hand held portable radios, operating on a frequency of 143.15 MHz. One of these hand held radios is given to the Condron Field control tower to insure the runway area can be rapidly cleared for incoming or outgoing aircraft. Others of these radios are carried by the target launch crew, and by each remote pilot or helicopter technician. The base station radio is installed in the Mission Control Van.

Core Instrumentation Subsystem (CIS)

The center of RADES is the CIS and the RMCS. Scenario generation is accomplished using a color graphics processor and the scenario generation software system. The Scenario Generation

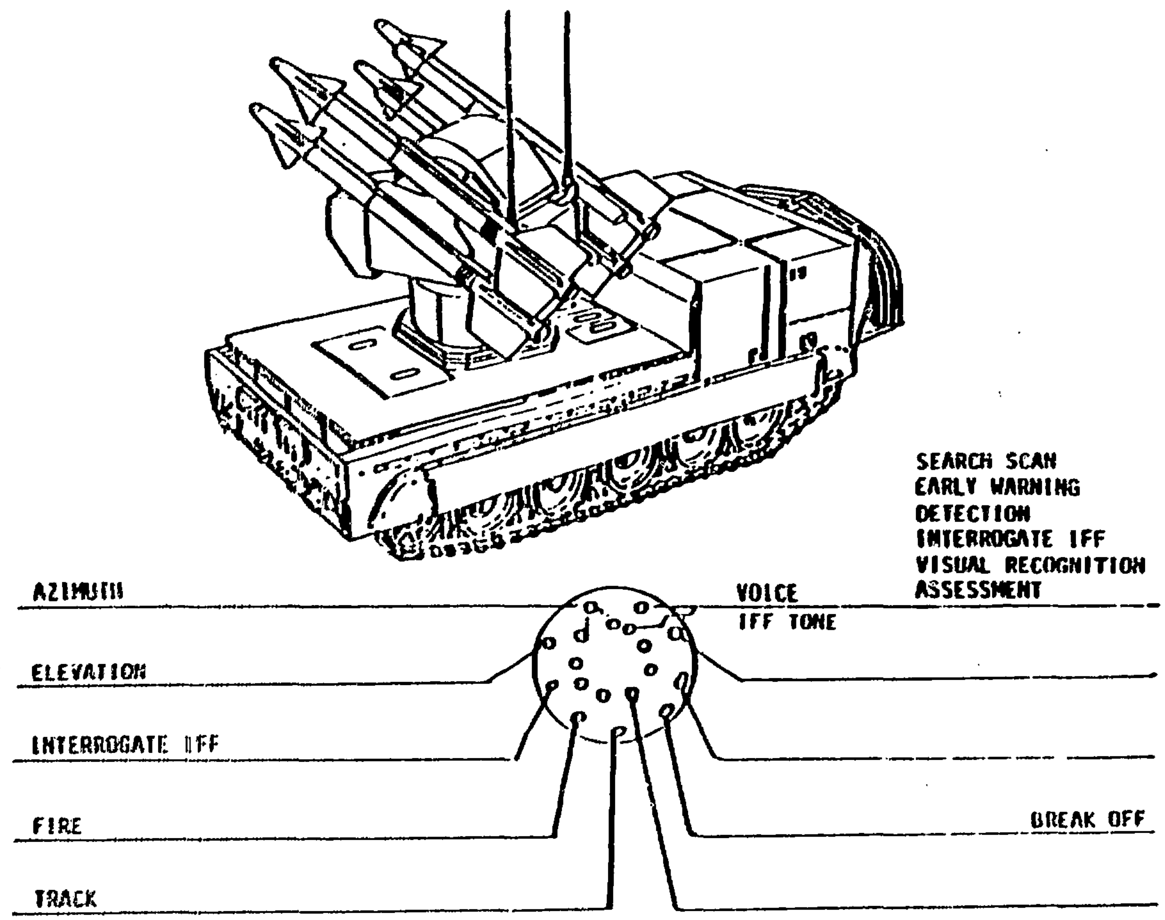


FIGURE 4. SCHEMATIC OF CIRCUIT TAP FOR CHAPARRAL

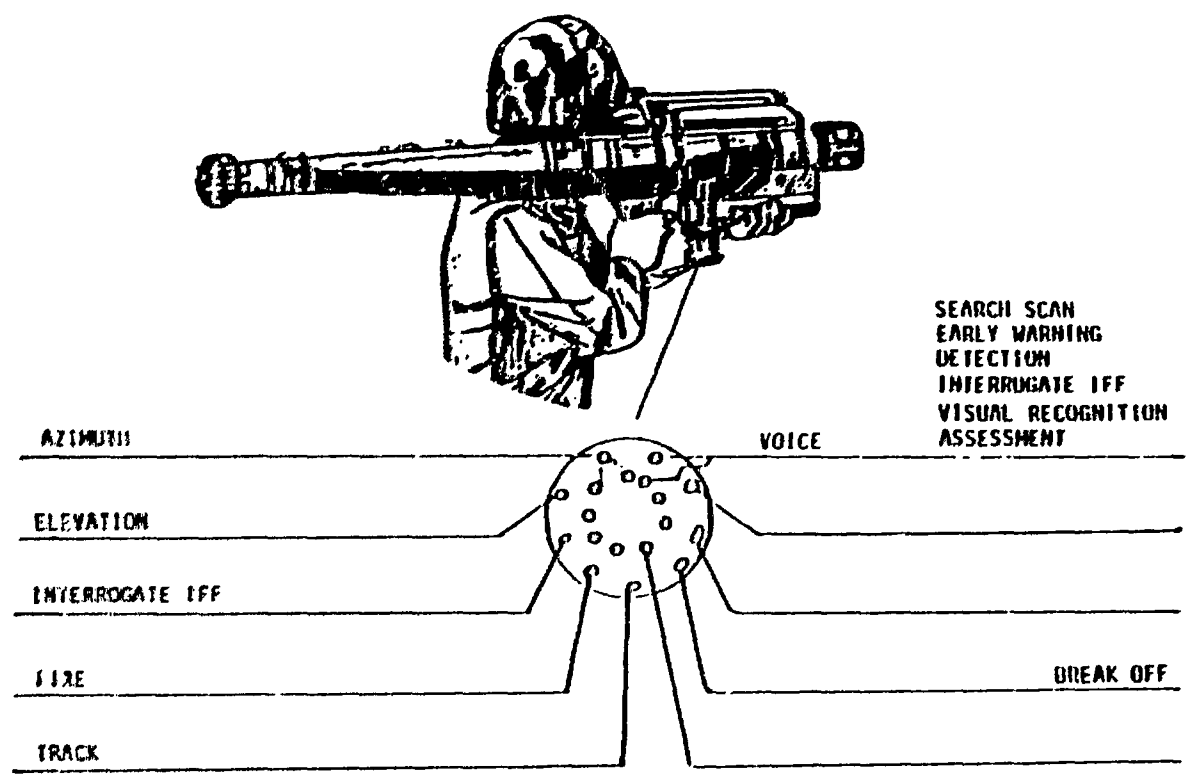


FIGURE 5. SCHEMATIC OF CIRCUIT TAP FOR REDEYE & STINGER

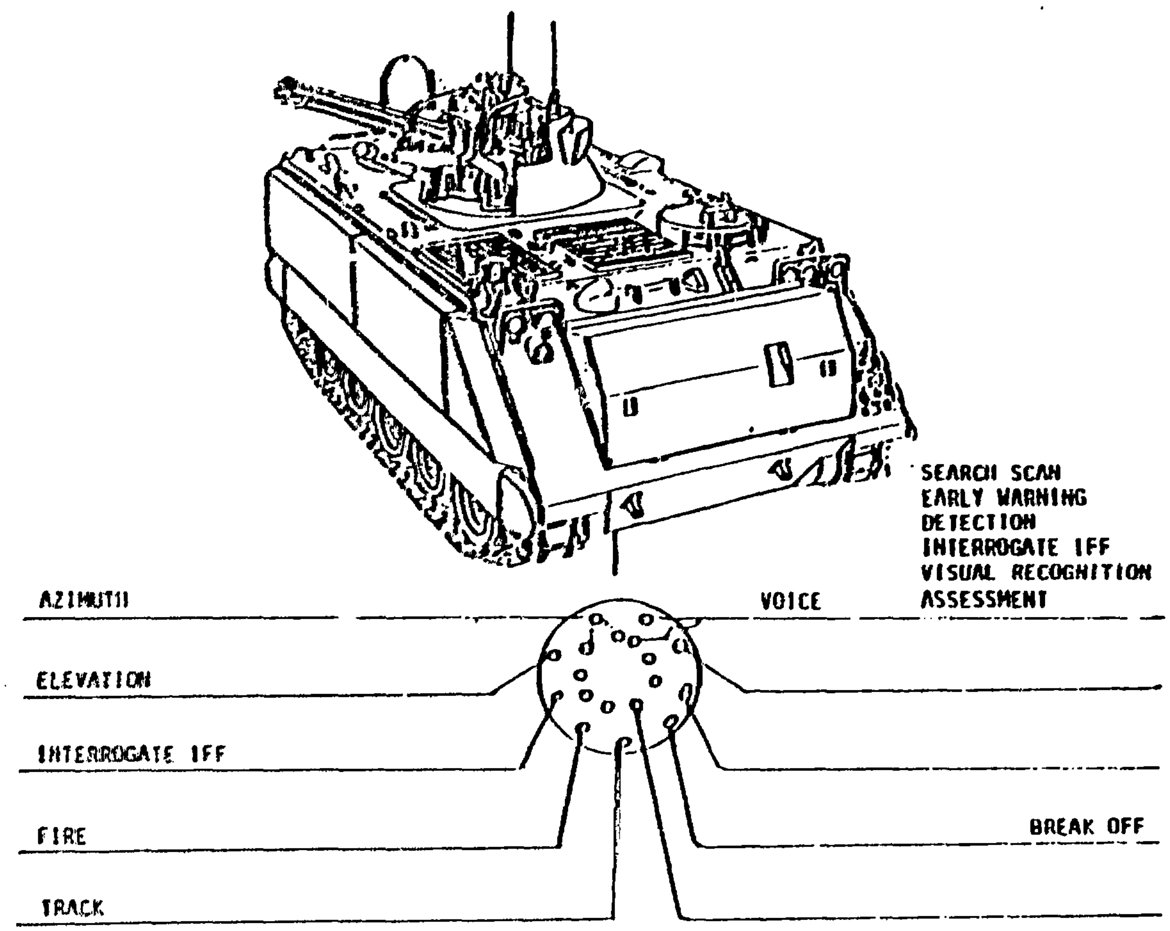


FIGURE 6. SCHEMATIC OF CIRCUIT TAP FOR VULCAN.

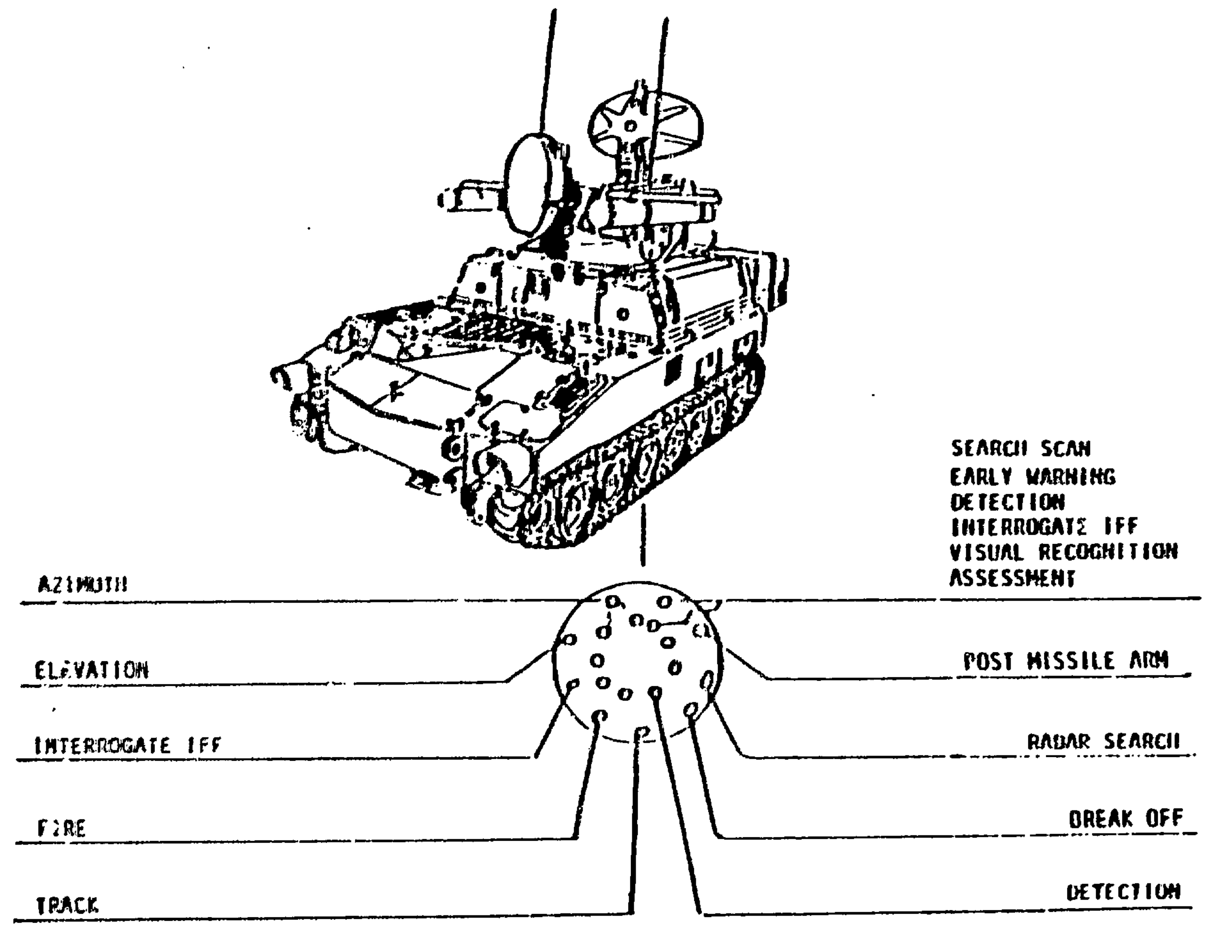


FIGURE 7. SCHEMATIC OF CIRCUIT TAP FOR ROLAND

Center (SGC) and the remote site Mission Control Van use identical microprocessors. This allows scenario generation and editing to be done either at the SGC or at the remote RADES field site.

Scenarios include flight path and helicopter control information and target presentation data files. Scenarios are saved and transported to the test site on magnetic floppy diskettes.

Major hardware components of the CIS are:

1. A minicomputer.
2. A microprocessor.
3. A color graphics system.
4. A master ground station.
5. Color graphics monitors.
6. Alphanumeric operator terminals.
7. A dot matrix printer.
8. A Universal Test Panel (UTP).
9. An on-board power generator.
10. A power purification device.

Allocation of CIS software modules to either the minicomputer or the microprocessor depends on the realtime or background task nature of module functions. The minicomputer, being faster, handles the majority of realtime functions, while the microprocessor performs as an intelligent front-end for the minicomputer, and acts as a background task processor. All scenario generation, trial background file generation, crew demographics, data base management, and data analysis functions, are handled by the microprocessor. The minicomputer and the microprocessor share the functions of system initialization, interactive test and calibration, and realtime data acquisition.

RDMS Interfaces with the CIS

The primary connection between the RDMS and the CIS is a serial interface joining the master ground station with the Transponder Integration Equipment (TIE) unit, and the TIE with the minicomputer. Once every 200 milliseconds the minicomputer interrogates the TIE unit. Three new TOA messages are requested from the master and slave ground station which collected the TOA messages in the previous 200 milliseconds. In this way the CIS minicomputer retrieves inputs to calculate the position of the flying target aircraft.

A second interface connecting the RDMS with the CIS is that interface joining the microprocessor to the UTP and the UTP with the helicopter stand system. Helicopters are under the control of the microprocessor. Every 200 milliseconds the minicomputer

checks to see if any raise, lower, or rotate commands are to be transmitted to the helicopters. In that same cycle, the minicomputer also checks for an effects flag, cueing the release of a smoke kill signature on one of the targets. If one or all of these conditions exist, the minicomputer passes a message to the microprocessor telling it to transmit these signals to the appropriate helicopter stand.

The UTP allows the CIS Computer to verify and test all outputs from the microprocessor to the helicopter. The transmission time between the computers and to helicopter stands have been adjusted, so that inappropriate time-lags are not added to crew engagement times. For example, round flight times are controlled to prevent unrealistic lags in kill-effects signature releases.

A third interface between the CIS and the RDMS connects the microprocessor and the effects release radio control transmitter. This interface communicates engagement effects release signals to flying target aircraft. When the minicomputer assesses a kill, it then calculates a round flight time delay and sets up a release message timed to adjust for transmission delays. When the designated cycle is reached, the message is transmitted to the microprocessor, commanding the dedicated radio transmitter to uplink the release command to the flying target. This results in the injection of oil into the engine exhaust system, causing smoke to stream from the target. If the target evades, such that round and target intercept would not occur, the effects release message is canceled and a no-kill is assessed. Effects release can be manually controlled by a target pilot, when commanded to release smoke. This command is issued by radio message when the graphics display indicates a kill.

RMCS Interfaces with the CIS

The primary interface between the CIS and the RMCS is that joining the weapon system with the UTP and the microprocessor. It is through this interface that all weapon system data enters the computer system, except for two key data elements, the detection and identification engagement events.

All tactical voice messages are entered into the digital data base via a voice message switch. The message switch is a device which senses signal amplitude on the voice net and writes a pulse train into the digital data record. When the signal amplitude is above a threshold level the message switch writes a binary "one" into the data record for the current 200 milliseconds. Otherwise the message switch writes a zero into the data record.

When an operator hears the detection or identification announcement, he enters a keystroke indicating the occurrence of the detection or identification event. Since the message switch

has written a pulse train for each message into the data records, the realtime computer system is able to correct for entry lag times by matching the detection or identification event keystroke entry with the last message start time.

Remaining weapon system event data captured by RADES are limited to two forms: discrete events, such as acquisition, track, search radar activation, etc.; and analog signals, such as azimuth and elevation. The microprocessor forms all sensed weapon events into a data stream within a realtime memory buffer and then waits for the minicomputer to request these data from it. The resulting message passed from the microprocessor to the minicomputer transfers the complete status of the weapon system for the current 200 milliseconds of engagement.

Internal CIS Interfaces

Within the Core Instrumentation Subsystem there is one bi-directional interface and one uni-directional interface of critical importance. The bi-directional interface is a serial interface between the minicomputer and the microprocessor. Once every 200 milliseconds the minicomputer transmits track data and target effects data to the microprocessor, and the microprocessor returns weapon event data to the minicomputer.

The uni-directional interface is the Direct Memory Access (DMA) connection between the microprocessor and the graphics processor. This uni-directional interface is used to pass the track updates to the graphics processor. The graphics processor then uses the updated track file to generate the latest graphic image of the target flight situation to the air traffic controller, who relays target flight information to the pilots.

Serially connected to the minicomputer is the TIE unit, magnetic tape transport and the operator's console. Serial connection is also used to interface the microprocessor to the dot matrix printer. All disk drive connections used by both the computers are parallel interface connections. The minicomputer uses an 80 million byte hard disk drive, while the microprocessor uses two 1 million byte eight inch floppy drives.

METHOD

This study was conducted during April and May of 1984 in a relatively flat, desert environment. The test was conducted during clear weather, daylight conditions. No terrain masking of fixed wing aircraft on long, low-altitude approaches occurred.

The test was conducted using four types of aircraft. Two fixed wing targets (friendly F-16 and hostile MIG-27) and two rotary wing targets (friendly U.S. Cobra and hostile Soviet Hind-D) were used. Rotary wing aircraft were capable of simulating a vertical pop-up, hover, and descent maneuver of scenario-defined duration. Fixed wing aircraft flew at the fullscale equivalent of 420 knots, while stand-mounted helicopter targets were stationary. Fixed wing aircraft averaged altitudes of 250 feet, simulating a fullscale altitude of 1750 feet. Stand mounted helicopter targets rose from a defilade position to a fully extended altitude of 15 feet, simulating a fullscale altitude of 75 feet, with the majority of the lifting hardware remaining hidden.

Eight different fixed wing scenarios, and eight different stand helicopter scenarios were used. Four I-Chaparral crew and six Stinger teams participated as subjects. Figure 3 depicts the four basic flight paths for fixed wing aircraft. There were two flight path presentations for each crew, once for hostile and once for friendly aircraft types. Table 1 lists the stand helicopter target raise, hover, and lower durations for each of the eight pop-up helicopter scenarios. Independent scenarios were presented to each crew in random order to control for transfer effects. Weapon malfunctions, weather conditions, etc., interrupted the testing at random intervals such that crews did not always receive all 16 scenarios. The random distribution of these occurrences was not considered detrimental to the overall test objectives. Offset (the range of the fixed wing target from the weapon at the closest point to the weapon) for the flight paths averaged 1,043 meters (fullscale).

Soldier demographic profiles and selected vision measures were obtained before each test. Demographic information was recorded for all soldiers comprising each weapon system crew, while vision measures were limited to squad leader and gunner personnel.

Two equivalent forms of the Snellen eye chart were used to measure visual acuity. Acuity was measured at a distance of 20 feet ("medium acuity") and at 100 feet ("far acuity") from the soldier's eye to the chart. The stimulus sizes on the eye chart were increased for the farthest of the two distances to keep the visual angle subtended constant. Soldiers' read selected sections of the eye chart to the data collector who manually recorded their scores for later keyboard entry into the RADES soldier data base. Scores were determined on the basis of the smallest line that the subject could read, which corresponded to 20/20, 20/15, or 20/10 vision.

A Polarized Vernier Optometer was used to measure the dark focus of the squad leader and gunner. Soldiers viewed a display of light emitting diodes representing line segments. Two line segments were positioned across the same plane with a third line segment positioned between them. The third line segment was

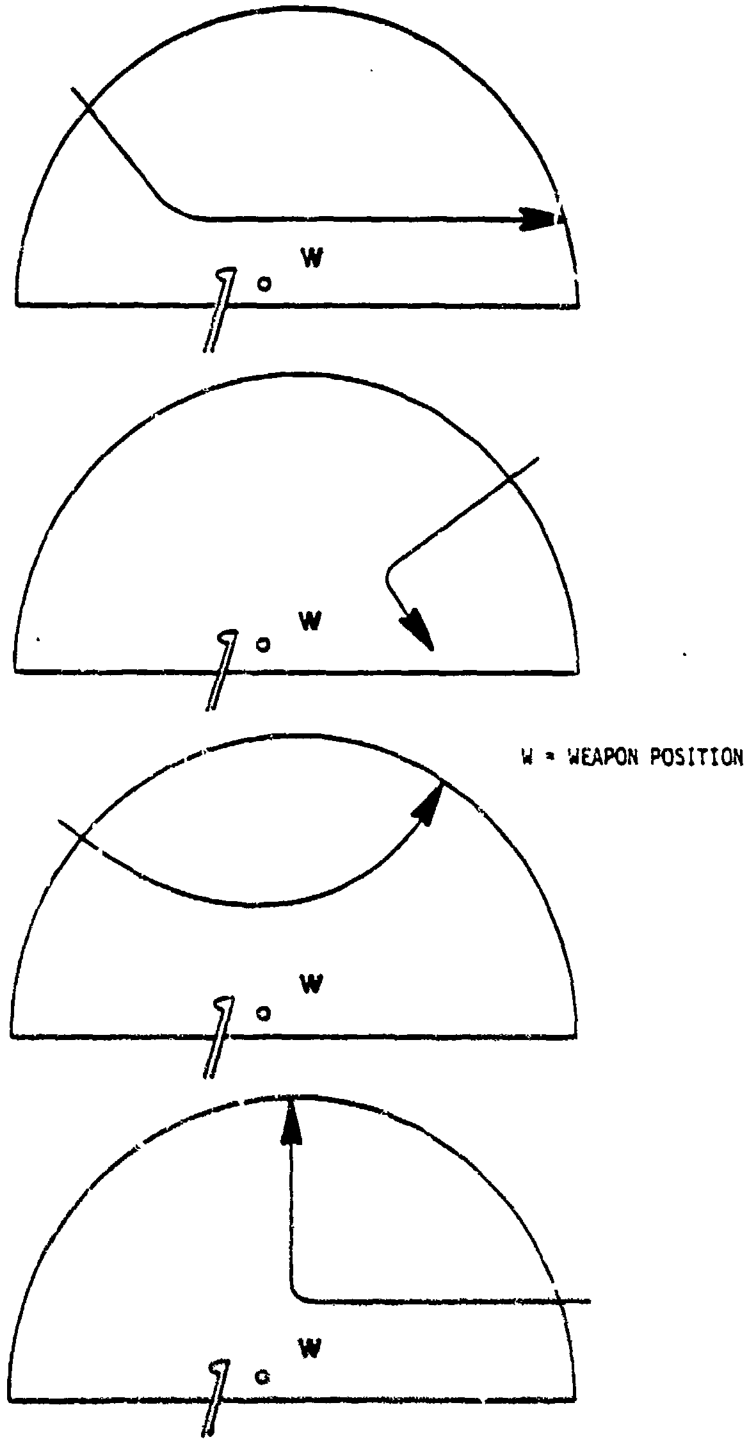


FIGURE 6. FOUR BASIC FLIGHT PATHS FOR FIXED WING RADES TARGETS
NOTE: MEAN OFFSET WAS EQUAL TO 1.043 METERS FULL SCALE

Table 1

Helicopter Scenario Raise and Lower Times

SCENARIO	ID NO.	TARGET INTENT	RAISE TIME	LOWER TIME	ORIENTATION
1	17	FRIEND	9 SECS	29 SECS	N -> S
	17	THREAT	30 SECS	60 SECS	N -> S
	17	FRIEND	70 SECS	100 SECS	N -> S
2	18	THREAT	9 SECS	39 SECS	N -> S
	18	FRIEND	45 SECS	60 SECS	E -> W
	18	FRIEND	85 SECS	115 SECS	N -> S
3	19	FRIEND	18 SECS	53 SECS	N -> S
	19	FRIEND	60 SECS	90 SECS	S -> N
4	20	FRIEND	10 SECS	80 SECS	N -> S
	20	THREAT	10 SECS	80 SECS	N -> S
	20	FRIEND	10 SECS	80 SECS	N -> S
5	21	THREAT	9 SECS	39 SECS	N -> S
	21	FRIEND	40 SECS	80 SECS	N -> S
	21	THREAT	100 SECS	130 SECS	N -> S
6	22	FRIEND	9 SECS	29 SECS	N -> S
	22	THREAT	30 SECS	60 SECS	E -> W
	22	THREAT	70 SECS	100 SECS	N -> S
7	23	THREAT	13 SECS	33 SECS	N -> S
	23	THREAT	35 SECS	40 SECS	S -> N
8	24	THREAT	10 SECS	40 SECS	E -> W
	24	FRIEND	10 SECS	40 SECS	E -> W
	24	THREAT	10 SECS	40 SECS	E -> W

manually adjusted to appear as if it were moving up or down. The stimulus diodes flashed after each manipulation to prevent the soldier from adjusting his accommodation to the stimulus. The soldiers responded by stating that the stimulus line appeared to be above, below, or on the same plane as the other displayed reference lines. Alternating test trials moved the stimulus line above and then below the reference lines, until the soldier identified the three lines as residing on the same visual plane. This position represented the resting accommodation of the soldier's vision system in diopters. For RADES the dark focus scores were converted to positive interval scores by adding a constant value of 10 to the diopter scale indication. Only left eye dark focus was measured due to limitations of the optometer.

Visual contrast sensitivity was measured according to procedures recommended by Ginsburg and colleagues (Ginsburg, Bittner, Kennedy, & Harbeson, 1983; Ginsburg, Easterly, & Evans, 1983). Contrast sensitivity is usually measured by presenting observers with a repeated pattern of light and dark bars varying in luminance contrast and spatial frequency. Contrast is defined as $C = (L_{max} - L_{min}) / (L_{max} + L_{min})$, where Lmax is the luminance of the light bars and Lmin is the luminance of the dark bars. Frequency is measured in cycles per degree of visual angle. Visual angle is defined as $F = \text{tangent } (S/D)$, where S is the size of the object and D is the distance of the object from the observer's eye.

The stimuli consisted of square-wave gratings varying in seven levels of contrast (0.017, 0.039, 0.064, 0.087, 0.111, 0.136, 0.155) and five levels of frequency (1, 2, 4, 8, and 16 cycles per degree of visual angle). Luminance of the stimuli was measured and calibrated for a viewing distance of 3.12 meters. Stimuli were presented on a graphics monitor (512 x 512 pixel resolution, raster-scan) to a soldier seated with his head positioned in a chin rest. The stimulus display at the monitor screen measured 0.191 meters in horizontal extent by 0.165 meters in vertical extent. All gratings were vertically oriented. The total numbers of complete cycles of the grating patterns presented left to right on the display screen were 3.5, 7, 14, 28, and 56 cycles per display width for spatial frequencies 1, 2, 4, 8, and 16, respectively. Troops were tested individually using the method of increasing contrast. Contrast was incremented every five seconds, until detection was announced, or until maximum contrast was reached. The contrast level at detection was automatically recorded. The procedure continued until a contrast sensitivity threshold was determined for each frequency. A subject's score was the mean of the contrast sensitivity thresholds.

After completing the demographic interview and vision measure test battery, the crews were oriented to the air defense situation via an operations order, then transported to their weapon system. Weapon systems were held constant by changing the crews and retaining the same weapon for all subsequent crews.

After the crew arrived at the weapon system location, an alerting message was transmitted to them from the RADES vans over a field telephone. The alerting message set the state of alert ("condition red") and weapon control status ("tight"). Cued by a realtime clock, the alert preceded target availability by approximately 1 minute. Thirty seconds before an aircraft target became available, a voice cueing message was transmitted to the crew. The cueing message told the crew if the target was high or low, and gave the approximate o'clock position of target approach relative to the weapon azimuth. The purpose of the cueing message was to orient the crewmen to the target and to minimize the visual search component of the engagement sequence.

No special steps or changes from normal weapon system engagement procedures were introduced to cause the weapon or the soldiers to behave any differently than they would if they were engaging targets without RADES present. When a target detection or identification announcement was made by the crew, it was recorded and time-tagged from a keyboard entry made at the RADES vans by an operator listening in on the field telephone net. When the soldiers initiated a friend or foe interrogation (IFF) challenge, established lock-on, or fired, the event was recorded and time-tagged automatically through the RADES weapon system circuit taps.

PARTICIPANTS

Crews for each of the two weapon systems were selected on the basis of their availability (i.e., a random sample was not possible). Four Chaparral crews (4 or 5 men each) and six Stinger teams (2 men each) were tested. Stinger teams were drawn from the 3rd Armored Cavalry Regiment. Chaparral crews were drawn from the 4th of the 1st Battalion of the 11th Air Defense Artillery Brigade. Soldiers had a mean age of 24 years and varied plus or minus 5 years about the mean age. They had a mean paygrade of E-4, an average civilian schooling history of 12 years, and a mean time in service of 44 months. Stinger soldiers averaged 9 to 10 months time in their present battalion, but varied plus or minus 8 months about that mean. Stinger soldiers tested had been members of their present platoon for 8 to 9 months on the average, but varied plus or minus 7 months about the mean. Soldiers had been in their present crews for an average of 4 months, but varied 3 to 4 months about the average. Table 2 presents crew demographics by weapon type.

The administered visual abilities descriptive measures were: Contrast sensitivity, dark focus, far acuity, and medium acuity. Contrast sensitivity is a measure of the ability to discriminate differences in luminance between adjacent visual fields (Ginsburg, Bittner, Kennedy, & Harbeson, 1983; Ginsburg, Easterly, & Evans, 1983). Dark focus (Leibowitz, Hennessy, & Owens, 1975; Owens, 1984) is a measure of the range (distance) of

focus given the absence of a target image upon which to focus. Far acuity is a measure of the ability to resolve small differences in high contrast, patterned, stimuli at a distance of 100 feet. Medium acuity is a measure of the same visual acuity at a distance of 20 feet. Both medium and far acuity assumed good, as opposed to adverse, viewing conditions, where adverse viewing conditions include night, degraded daylight, instrumented viewing, and empty field viewing situations. Subjects participating in this test were considered to have superior visual capabilities.

Table 2

Descriptive Statistics for Crew Demographics
(Includes Squad Leader and Senior Gunner Only)

	I-Chaparral (4 crews)			Stinger (6 teams)		
Variable	N	Mean	SD	N	Mean	SD
Age	4	25.4	3.7	6	22.5	1.8
Rank	4	3.8	0.6	6	4.0	0.3
Education	4	11.9	0.4	6	12.2	0.6
Months in Service	4	56.2	25.1	6	29.3	7.1
Months in Batallion	4	7.4	3.0	6	10.1	4.0
Months in Platoon	4	5.9	3.7	6	10.1	4.0
Months in Crew	4	3.9	2.6	6	5.2	3.5

Table 3 provides descriptive statistics for the visual ability measures for both Stinger and Chaparral troops.

Table 3

I-Chaparral and Stinger Soldier Vision Test Results

	I-Chaparral (4 crews)			Stinger (6 teams)		
	N	Mean	Standard Deviation	N	Mean	Standard Deviation
Contrast Sensitivity (measured in units of luminance contrast, as defined in body of report)						
Squad Leader	4	0.022	0.003	6	0.021	0.003
Gunner	4	0.023	0.005	6	0.026	0.007
Dark Focus (measured in units of diopters plus the constant 10)						
Squad Leader	4	10.37	0.42	6	10.62	0.43
Gunner	4	10.42	0.39	6	10.45	1.20
Far Acuity (subject's acuity at 20 feet compared to the population norm at X feet)						
Squad Leader	4	12.50	2.89	6	10.83	2.04
Gunner	4	12.50	2.89	6	10.00	0.00
Medium Acuity (subject's acuity at 20 feet compared to the population norm at X feet)						
Squad Leader	3	15.00	0.00	6	12.50	2.74
Gunner	3	13.33	2.89	6	13.30	2.58

MEASURES

This section presents target, weapon, crew, environmental, and control variables and constant conditions relevant to the RADES Validation test. Each variable or constant is named, its data type (numeric or character) is given, and its method of capture and tolerance levels are specified, where needed.

Target Stimulus Variables and Constants

- Stand Helicopter Position (X, Y, Z; T): numeric constant; initialized to plus or minus eight feet in the X, Y coordinate plane before problem start; pre-set in Z variable coordinate before trial (Z = elevation). The Z coordinate was under computer control, and initialized as the fixed time (delta T) for the target to rise above the defilade state and become available for detection.

- Flying Target Position (X, Y, Z; T): numeric variable; captured (updated) once each 200 milliseconds to an accuracy of plus or minus eight feet in the X, Y, and Z coordinate dimensions.

- Flying Target Velocity (V): numeric variable, calculated; computed once every 200 milliseconds for each flying target track; refers to relative forward ground gaining velocity, as opposed to airspeed, in X, Y, Z coordinate dimensions.

- Target Azimuth: numeric variable; that azimuth (in degrees) which would align the target with the weapon gunner's reticle. Target Azimuth is updated once every 200 milliseconds (Note: not available for the Stinger weapons during validation). Target azimuth is measured accurate to one degree.

- Target Range: numeric variable; the straightline distance in feet from the current X, Y position of the weapon system to the target. Target range was updated once every 200 milliseconds.

- Target Radar Signal Reflectance: numeric; held constant for each flying or stand helicopter target, by the application of

specific amounts of radar reflective tape applied to the leading edge of fixed wing targets or to helicopter rotor blades.

- Target (Smoke) Plume Signature: eliminated from all targets and thus held constant; the rationale being that while smoke signatures can be an aid to target detection, the assistance is a false means of detection, not replicatable under most combat conditions. In full scale situations smoke emissions, when visibly present, vary as a function of aircraft states of maintenance and the aircraft fuel in use.

- Target Aspect Ratio: numeric, controlled constant; referring to such relationships as the ratio of wingspan to length; this factor was controlled by insuring that any deviation from host aircraft structural design was replicated in all subscaled targets representing that host aircraft (i.e., in wings, engine, fuselage and tail).

- Target Attack and Flight Profile: refers to the representativeness of the target flight-path to threat or friendly tactics flown under actual fullscale conditions. Controlled by planning both friend and foe air missions as full scale, actual operations and then scaling the flight-paths to 1/7 scale for fixed wing targets and to 1/5 scale for helicopter targets.

- Flight-Path: numeric, control variables; refers to the degree to which any scenario can be repeated in X, Y, Z, V dimensions in multiple trials. In RADES the planned flight and achieved flight were compared for every 200 milliseconds of flight as a trial replication control process.

- Target Availability for Engagement: sensed event variable; two types of target availability were measured. First, when a flying target reached that range boundary (X, Y point) pre-assigned in scenario design, the software system assessed that event from position tracking input signals within plus or minus 200 milliseconds of event occurrence. Second, when each stand helicopter was emplaced and calibrated, the time required to emerge completely from its defilade position was input as a fixed

constant to the computing system. When the scenario-specific raise time was reached (computed constant plus actual raise time), the helicopter became available for engagement.

- Aircraft ID Number: numeric variable; each target was assigned a unique identity number to control for aircraft (fixed-wing or helicopter) specific effects; entered once for each scenario trial.

- Aircraft Type: categorical variable; for fixed wing targets either MIG-27, or F-16 and for stand helicopters either HIND-D or Cobra.

- Type of Flight: nominal variable; where categories were limited to "fly-by" (i.e., no ordnance maneuver) or "attack in vicinity."

- Helicopter Command Times: numeric variable; "time of raise" command initiation, "time of fire", and "time of lower" for each respective helicopter as initialized prior to the start of each set of scenario-specific trials.

Weapon System Response Variables and Constants

- Weapon System Position: numeric, fixed constant; updated once per set of trials. A single weapon system position (X, Y, Z) was initialized to within plus or minus eight feet of the actual weapon location.

- Weapon System Type: categorical variable; before each set of scenario-specific trials, the weapon system type (i.e., Chaparral, or Stinger) was initialized.

- Weapon System Azimuth Orientation: numeric variable; measured in degrees; zero degrees equals the front of the mount. Azimuth was accurate to within plus or minus 1 degree and was sampled once every 200 milliseconds. These data were not taken for Stinger.

- Weapon System Elevation: numeric variable; measured in degrees (0-90), and accurate to within plus or minus 1 degree. Elevation data were sampled once every 200 milliseconds for Chaparral weapon systems. These data

were not captured for Stinger. This should not be confused with "superelevation" event data only captured for Man-Portable Air Defense (MANPAD) weapon systems.

- Visual Target Detection: numeric interval variable; when any crewman detected the target visually, and announced "contact", the operator entered a function keystroke immediately, indicating the occurrence of the visual detection event. Software identified the actual time of the "contact" message and corrected for entry lag by placing the event at the first 200 milliseconds of the voice message signal.

- Target Track or Target Lock-On: numeric, time-interval variable; when the gunner gained track or lock-on (e.g., ready to fire light, lock-on tone, etc.) the signal was sensed and the event was logged to within 200 milliseconds of the occurrence of that event. Loss or gain of track or lock-on was logged in the same way.

- Identification Friend or Foe (IFF) Interrogation: numeric, interval variable; when the crewman activated the IFF switch, the signal was sensed and logged within 200 milliseconds of switch activation.

- Visual Aircraft Identification: numeric, interval variable; when a crewman identified the target aircraft as friendly or hostile, or as a particular model, the RADES operator heard the announcement over the tactical intercom voice circuit, and immediately entered that function keystroke logging the event and time. Just as was done for visual target detection, RADES software automatically paired the event with the voice message announcing it and moved the time of event occurrence to the first 200 milliseconds of that message.

- Superelevation: numeric interval variable; this variable was captured for the Stinger Weapon systems only. When a Stinger gunner superelevated his weapon, the event was sensed within 200 milliseconds of event occurrence and time logged.

- Weapon Fire or Launch: numeric interval variable; when the gunner depressed the trigger switch to fire rounds or launch missiles, the event was sensed and logged within 200 milliseconds of actual event occurrence.

- Engagement Effects Assessment: nominal and time-interval variables; after the fire or launch event was sensed, the RADES software system identified the target being engaged, checked to ensure that the target was within weapon system range, and that track or lock-on was active at the time of trigger pull. Then the software synthetically flew the round(s) to target intercept and assessed either a kill or a miss. If a kill was assessed, the kill was logged as a "1", and the kill-designating smoke was released from the target by radio control signal. If a miss was assessed, a "2" was recorded. The time of kill or miss was also logged for use in statistical analysis and score calculation.

- Reattack or Break-Off: interval variable; once a "miss" or "kill" was assessed the weapon was monitored for the occurrence of reattack, or "break-off" from engagement. These data were not captured for Stinger weapons as only a single firing of each is possible.

- Alert Inputs: interval variable; conditional text data air defense warning, state of alert, hostile criteria, and weapon control status. Information describing these conditions was read to the crew by the Test Director over the weapon system field telephone or intercom. This was done before the start of each scenario trial to control crew preparation times. The time of alert transmission was a recorded control variable.

- Cueing Input: interval variable; a cueing message (when designated by the governing scenario) was given to the crew at a fixed time point. The time of message transmission was controlled by a realtime (negative exercise time) count-down clock dedicated expressly to this function. When the cueing message had been transmitted, the Test director depressed the function key logging the time of message transmission.

- Communications (Voice Net) Status: nominal variable denoting presence of an analog signal; whenever a true voice message occurred over the weapon system intercom or field telephone system, a status bit was set active high, and remained active high until the voice message was fully terminated. Pauses, "net keying", line noise, and spikes were filtered and did not cause the "COM" status bit to be set to one. The RADES computing system sampled "COM Status" once every 200 milliseconds.

Soldier Variables and Constants Summary

- Soldier ID Number
- Soldier Age
- Soldier Battalion Designation
- Soldier Battalion Number
- Soldier Platoon Designation
- Soldier Platoon Number
- Soldier Current Assignment
- Soldier Paygrade
- Soldier Primary Military Occupation Specialty
- Soldier Secondary Military Occupation Specialty
- Date
- Soldier Years of Civilian Schooling
- Soldier Time in Service
- Soldier Time in Battalion
- Soldier Time in Platoon
- Soldier Time in Crew

Environmental Variables Summary

- Dry Bulb Temperatures
- Wind Speed
- Wind Direction
- Relative Humidity
- Barometric Pressure
- Range of Visibility

TEST RESULTS

RADES test results presented in this section reflect engagement event times or target ranges at event occurrence, visual aircraft identification accuracy, threat kills, and fratricides. In the last part of this section, RADES validity is assessed in terms of prior reported test results from SHORAD tests, and considering calculated calibration criteria for fixed wing aircraft scenarios.

Key SHORAD engagement event results discussed are: (1) declaration of target available for detection; (2) first visual target detection announcement; (3) Identification Friend or Foe (IFF) initiation; (4) fire control system lock-on; (5) visual aircraft identification announcement; (6) superelevation of the weapon (Stinger only); (7) fire; and (8) break-off from engagement.

Engagement event range or time of occurrence, accuracy of identifications, and assessed engagement effects are of direct interest in RADES as measures of performance efficiency and effectiveness. The RADES validation question was chiefly concerned with the representativeness of event times, ranges, assessed accuracy of identifications, threat kills, and fratricides. Engagements early in time, or far in range, are considered more efficient than late, or near, engagements. Effectiveness on the other hand is evidenced more in terms of threat kills, fratricides, and associated correctness of visual aircraft identifications, regardless of the time and range of its occurrence. Any assessment of RADES must by necessity concern itself not only with efficiency of engagement measures, but with effectiveness as well.

RADES events are derived differently for fixed wing and rotary wing targets. Rotary wing events are a function of time from availability which commences with the computer's command to rise. Since helicopter stands are fixed, only the times are

relevant, as ranges will not vary. Fixed wing events are derived according to the range of the target from the weapon. Target availability occurred when the flying fixed wing target was approximately 10,500 fullscale meters from the weapon. Since fixed wing flights are not replicable with perfect accuracy, the time of event occurrence was of little importance, whereas the ranges are captured for every event with precise accuracy. Thus, the engagement events for rotary wing trials were time-based and the events for fixed wing trials were range-based. This also made the data more compatible when making comparisons with other test results.

Throughout the presentation of results in this report, one will note that the number (N) of observations changes across dependent variables. This is due to the fact that not all crews performed all engagement actions on every trial. If a crew omits an engagement step, that step cannot be recorded by RADES. For example, as shown in Table 4, Stinger teams made more "identification announcements" (N=31) than "detection announcements" (N=28). In addition, all engagement actions were not relevant on all trials. For example, crews did not fire at all aircraft detected, since some aircraft were friendly. Hence, the N for "fire" will be smaller than that for "detection".

Rotary Wing Engagement Event Times

Rotary wing engagement scenarios contained up to three targets presented in a series, mixing threat and friendly aircraft such that troops could not determine in advance which target would appear next. Engagement event times for first, second, and third targets are presented in Tables 4 through 6. Response times reported in these tables represent the time, in seconds, from helicopter target availability until each engagement response. The reduction in number of cases for first, second, and third targets occurred because of target stand malfunctions which resulted in the failure to raise or lower targets as the scenario scripted.

The straight-line range to the stand-mounted helicopter targets from the weapon position was held constant at about 2,000 fullscale meters. The orientation of the aircraft to the weapon (in azimuth) was held constant at 90 degrees or 270 degrees to prevent helicopter orientation effects on detectability or identifiability. Scenario-specified rotary presentation times were controlled by the RADES computer system.

Multiple Stinger engagement simulations require that the system be re-energized after each launch. During validation testing this process occurred more quickly than could be a reasonable approximation of preparing a second weapon. Thus, it is noteworthy that Stinger times for second target engagements

are probably too short to be representative of the real world. The I-Chaparral times might also be short due to the lack of a limit on time to select a different missile round. However, I-Chaparral second engagement time artifacts should be substantially smaller than those introduced in the Stinger tests because the missile round selection is estimated to require only 0.3 to 0.5 seconds during actual live-fire operations.

Table 7 presents independent samples (pooled variance estimates) t-test comparisons between I-Chaparral and Stinger for first target rotary wing event times. This table presents comparisons of elapsed times from target availability for critical "raw" engagement events (e.g., detection, interrogation, lock-on). In addition, this table presents comparisons of important "processed" engagement event times (e.g., ID minus detect, fire minus detect). The only significant differences found between Chaparral crew performance and that for Stinger teams was in raw detection and identification times. Stinger teams detected and identified RADES rotary wing aircraft earlier than Chaparral crews. This result is somewhat surprising in light of the fact that a Chaparral crew contains four or five pairs of eyes to search for aircraft, while a Stinger team contains only two. However, our available sample for this experiment was small, and we assume this difference represents subject differences. The processed-score comparisons examine differences in engagement times with raw detection times held constant. Using this performance metric, there were no differences found between Chaparral crews and Stinger teams.

The absence of differences between weapon systems for the processed scores is particularly interesting. It suggests that the time to engage RADES rotary wing aircraft, once they have been detected, is independent of weapon system -- for these two quite different weapons. Evidently, these engagement actions are controlled more by the nature of the stimuli, and the sensory and psychomotor processing of these stimuli by the troops, than by the specific operational procedures of the weapon systems themselves. For example, both the Chaparral and Stinger weapon systems require air defenders to detect, identify, and track the target visually. Also, both weapons employ auditory feedback of some sort to signal infrared lock-on. However, the purpose of this report is to demonstrate the validity of the RADES simulation. Further research will be needed to investigate issues such as these.

Table 4

Rotary Wing Engagement Event Response Times*
For First Pop-up Target

	I-Chaparral			Stinger		
Events in Seconds	N	Mean	Standard Deviation	N	Mean	Standard Deviation
Time of Visual Detection	9	16.9	9.2	28	10.9	6.7
Time of Interrogation	5	18.6	7.5	21	11.6	8.7
Time of Lock-on	9	22.7	14.4	21	23.0	9.2
Time of Visual ID	8	25.4	11.1	31	19.1	6.9
Time of Superelevation	-	----	----	22	26.9	8.5
Time of Fire	6	28.5	6.3	21	26.9	9.5
Time of Break-off	5	36.2	15.6	12	38.0	9.9

Mean period from Detection to Fire for I-Chaparral - 12 secs.
Mean period from Detection to Fire for Stinger - 16 secs.

* Times accumulate from first target availability until end of trial.

Table 5

Rotary Wing Engagement Event Response Times*
For Second Pop-Up Target

	I-Chaparral			Stinger		
Events In Seconds	N	Mean	Standard Deviation	N	Mean	Standard Deviation
Time of Visual Detection	5	32.8	10.9	19	41.4	16.0
Time of Interrogation	3	33.0	14.5	12	38.6	13.8
Time of Lock-on	4	34.0	13.5	18	46.9	18.3
Time of Visual Id.	4	35.0	11.7	19	45.7	17.3
Time of Fire	3	40.7	8.1	12	52.6	19.7
Time of Break-off	4	38.2	12.4	19	56.5	21.2

Mean period from detection to fire for I-Chaparral - 8 secs.
Mean period from detection to fire for Stinger - 11 secs.

* Times accumulate from first target availability until end of trial.

Table 6

Rotary Wing Engagement Event Response Times*
For Third Pop-Up Target

	I-Chaparral			Stinger		
Events In Seconds	N	Mean	Standard Deviation	N	Mean	Standard Deviation
Time of Visual Detection	4	68.2	26.7	13	81.3	19.9
Time of Interrogation	-	----	----	6	88.2	9.8
Time of Lock-on	4	83.2	31.7	13	92.1	17.5
Time of Visual Id.	4	85.5	21.2	13	86.9	21.4
Time of Fire	4	89.7	24.5	11	96.4	19.0
Time of Break-off	3	88.3	28.4	13	97.4	18.4

Mean period from detection to fire for I-Chaparral - 21 secs.
Mean period from detection to fire for Stinger - 15 secs.

* Times accumulate from first target availability until end of trial.

Table 7

Two Sample Independent Groups *t*-Test Comparison of I-Chaparral and Stinger Mean Event Times for Rotary Wing Engagements

Event	Statistic	Degrees of Freedom	2-Tailed Probability
Time of Visual Detection	2.05	35	$p < .05$
Time of Interrogation	1.64	24	$p > .10$
Time of Lock-on	0.08	28	$p > .10$
Time of Visual ID	2.03	37	$p < .05$
Time of Fire	0.40	25	$p > .10$
Time of Break-off	0.29	15	$p > .10$
Time of ID Minus Detect	0.20	34	$p > .10$
Time of Track Minus Detect	1.70	26	$p > .10$
Time of Fire Minus Detect	0.94	23	$p > .10$
Time of Fire Minus ID	0.71	24	$p > .10$

Fixed Wing Engagement Event Ranges

Table 8 presents the fixed wing engagement event ranges transformed to fullscale range equivalents. The fullscale event ranges are presented in kilometers following a long standing convention in Army air defense. Throughout this report, RADES fixed wing event ranges will be presented in fullscale kilometer equivalents.

Engagement ranges are of major importance in assessing the representativeness of RADES. Prior reported tests have concentrated on event ranges and on the accuracy of visual aircraft identifications made under different environmental conditions and experimental treatments. Therefore, fixed wing event ranges dominate external RADES validity criteria, and outweigh event time data in the determination of the validity.

These fixed wing event ranges for the Chaparral crews and Stinger teams were compared using a series of two sample, independent groups, *t*-tests (pooled variance estimates). The results of these comparisons are presented in Table 9. No significant differences were found between weapon systems for the key events of detection, identification, lock-on, and fire. These results support those presented earlier for RADES rotary wing aircraft, suggesting that performance in RADES is to some extent independent of the specific weapon system tested. This conclusion is not surprising given the dependence current FAAD weapons place on human perceptual capabilities for detection, identification, tracking, ranging, and infrared lock-on.

Engagement Effectiveness Results

RADES is concerned with the representative measurement of individual crewmembers and collective crew engagement efficiency and effectiveness. The weapon system is a controlled variable and is second in focus to the crew and behavioral issues influencing overall weapon system performance. Ballistics, on-board missile guidance, round launch failures, round jamming, double round feeds, etc. are not at issue in RADES. If the air defenders' engagement activities are correct (as indicated by the state of weapon circuitry), and the engagement would result in target intercept after round flight, a kill is automatically granted. The engagement effects signalling a kill are made to let the subjects of RADES tests know that engagement of the target has ended, or that it has not ended due to a miss. Thus, crew effectiveness and efficiency are the measurement goals, not weapon and round effectiveness, or machine failure rates. RADES makes no statements about whether or not the actual electromechanical weapon system would have accomplished such engagements successfully.

Engagement effectiveness was assessed for both the single fixed wing and the multiple rotary wing trials. Effectiveness measures included the percentage of targets killed, the percentage of valid identifications, the percentage of fratricides, and the percentage of attrition. Table 10 presents these effectiveness indices separately for both weapon systems and for both fixed and rotary wing targets. (Note: Unfortunately, all the raw data upon which the numbers presented in Table 10 were based were inadvertently destroyed before this report was finished. The scores presented in Table 10 represent early analyses of the effectiveness results and are therefore estimates of the actual values.)

Table 8

Fixed Wing Fullscale Engagement Event Ranges In Kilometers

	I-Chaparral			Stinger		
Events	N	Mean	Standard Deviation	N	Mean	Standard Deviation
Detection Range	14	8.5	1.6	23	8.1	2.5
Interrogation Range	4	8.4	1.0	17	4.7	2.7
Lock-on Range	14	5.5	2.7	22	4.2	3.6
Visual ID Range	13	6.6	3.2	21	5.5	2.6
Superelevation Range	--	---	---	16	3.3	1.3
Fire Range	13	3.4	2.6	21	3.3	1.3
Break-off Range	13	3.7	2.7	16	3.6	1.9

Table 9

Two Sample Independent Groups *t*-Test Comparison of I-Chaparral and Stinger Mean Event Ranges for Fixed Wing Engagements

Event	Statistic	Degrees of Freedom	2-Tailed Probability
Detection Range	0.51	35	$p > .10$
Lock-on Range	1.15	34	$p > .10$
Visual ID Range	1.13	32	$p > .10$
Fire Range	0.26	32	$p > .10$

Table 10

Engagement Effectiveness Outcome Probabilities*

Fixed Wing			
	I-Chaparral	Stinger	Overall
Events	Percent	Percent	Percent
Fixed Wing Kills	93	62	74
Fixed Wing Valid IDs.	80	69	73
Fratricides	53	42	46
Attritions	76	67	71

Rotary Wing			
	I-Chaparral	Stinger	Overall
Events	Percent	Percent	Percent
Rotary Wing Kills	93	82	84
Rotary Wing Valid IDs.	90	74	78
Fratricides	52	46	48
Attritions	82	67	70

* The raw data from which these percentages were calculated have been inadvertently destroyed. See note in body of report.

RADES VALIDATION ANALYSES

Introduction

Although many full scale field tests have been conducted in which ground observers and aerial targets have been used, relatively few investigated the full range of FAAD weapon crew engagement performances. Many of those tests that did involve FAAD crew performances were conducted under conditions quite different from those existing in the RADES validation study. Parts of six different field tests were identified as being comparable to the RADES study. Three were operational tests conducted by the Operational Test and Evaluation Agency (OTEA), one was conducted by TRADOC Systems Analysis Agency (TRASANA), one by the Combat Developments Experimentation Command (CDEC), and the last by the Human Resources Research Office (HumRRO) of George Washington University. The results of the RADES tests were compared to the results of the selected field tests as one approach to establishing the validity of the RADES facility as a FAAD system performance test bed.

An alternate approach was also used to test whether the results of the RADES studies exceeded the theoretical limits of FAAD system capabilities. FAAD system capabilities were defined as the combination of human performance and weapon performance times. This method was based on concepts presented by McCormick in "Human Factors in Engineering and Design" (McCormick, 1976; McCormick & Sanders, 1982). The theoretical analysis will be presented first.

DERIVED TIME LIMIT CRITERIA COMPARISONS

SAIC, using concepts relating to decision making, stimulus processing, and reaction time, proposed a method of validation analysis using established performance limits within which valid performance measures would be expected to fall. The approach detailed how pre-definitions of scenario flight path geometry and rate of target travel make it possible to calculate the earliest times and ranges at which engagement events (target detection, IFF interrogation, identification, lock-on, and fire) could reasonably occur. SAIC demonstrated how predetermined time systems parameters could be used to integrate estimates of human reaction times with weapon system engagement time and range criteria, to produce the latest time of occurrence by working backwards from the last possible point of target intercept.

SAIC's method incorporated a Scenario Time Line Generator (STLG) program produced by SAIC technicians. STLG modeled the fixed wing scenario flight paths used in the validation study, the characteristics of each weapon system, and the round flight

to target intercept. For the first applications of STLG it was assumed that crew member performance was perfect, that there was no variation in performance due to random or systematic performance errors. The performance boundaries established with this assumption were essentially representative of the weapon system capabilities without influence of normal operator performance variation. Such limits are the theoretical maximum for the weapon system. These STLG applications produced the earliest and latest time and range boundaries that could be expected for valid representation of real world performances for the validation scenarios. If RADES results were found to fall within the limits determined for each scenario, there would be no evidence to substantiate a conclusion that RADES results do not validly represent the results that would be found in a fullscale field test with similar conditions. If the RADES results were to be found to fall outside the limits, the conclusion would be that the RADES data are not representative of results that would be expected in the actual FAAD environment.

The first application of the STLG, however, provided idealistic limits and did not recognize the influence of normal variations in system performance due to factors influencing operator behavior. Therefore, a second iteration of the STLG was run. During this application, performance parameters present in the literature were integrated with the weapon system characteristics in establishing performance limits for each scenario. Putting the soldier back in the loop, so to speak, resulted in an extension of the performance times and shortened the performance ranges for each engagement event. Changes in the event parameters were due to variations in switch activation times, delay in voice announcements, directional movement delays and errors, reaction times in making decision choices, trigger pull differences, visual stimulus response processing time, etc.

The second run of STLG produced maximum, minimum, and average soldier event time and range boundaries for the earliest and latest possible points of event occurrence. Unlike deterministic machine criteria produced in the first application of STLG, man-in-the-loop criteria were statistically distributed in accord with the normal distribution (i.e., man-in-the-loop criteria are stochastic as opposed to deterministic in character).

It was not the purpose of STLG to predict perfectly machine dependent and man-in-the-loop event times and ranges. Instead, STLG was designed to generate boundaries, against which compromises to RADES's fidelity could be evaluated by comparing observed RADES test results with STLG criteria. Where a RADES test yields event times which occur before earliest time criteria, a fault is isolated and the particular circumstances leading to that compromise could be used to troubleshoot the source. Similarly, if RADES observed event times would occur later than the late STLG criteria, then a reverse problem would exist (i.e., engagement event occurrence beyond target

availability). If no STLG generated time or range boundaries were exceeded then the system could be said to be within established system tolerance limits.

STLG calculated early times and late times for all conditions and engagement perspectives. Earliest times were calculated forward from the earliest point of target availability for visual detection (time equals zero and range equals 14,000 meters) to the earliest time of fire, depending on the engagement condition (cued or uncued and human factors or no human factors). Since it was possible for detection to occur at ranges of 14,000 meters, detection was usually equal to time zero in STLG outputs. However, the STLG code used a search algorithm for the "no cueing" condition that assumed an azimuth sweep equal to the total search sector area and the residual from the right search sector limit back to azimuth alignment with the current position of the target.

Early time calculations for the "no man-in-the-loop" condition were performed almost totally by use of event range limits. Depending upon the weapon, the infrared acquisition, lock-on, and fire events were dependent upon target range. When range requirements were met, STLG would output the events and times of occurrence. When the human operator event times and ranges were calculated for earliest times, the fastest possible human responses were used and correspondingly optimal ranges of event occurrence yielded for each weapon type. The human response times used in the STLG were taken from the section entitled "Human Output and Control" in McCormick (1976, pps. 185-191). Detection was t=0 with cueing, with the time to perceive the target stimulus and to vocalize the "contact" announcement added to it (i.e., about 321 milliseconds to see the target and 112 to 352 milliseconds to announce). IFF interrogation and visual aircraft recognition were calculated by STLG together by adding a switch activation time of 112 to 252 milliseconds, time to discriminate target identity (i.e., 450 to 550 milliseconds) and time to announce the "engage" or "break-off" order (i.e., 112 to 252 milliseconds). STLG calculated time of fire as time to hear the command to "engage" and to pull the trigger or halt engagement (i.e., 112 to 252 milliseconds to hear the command and 112 to 252 milliseconds to fire or break-off). The round flight time to target and intercept time and range was also calculated and output by STLG, with checks to insure the target was still in range at time of round or burst pattern intercept. The two event time parameters were used for earliest and latest time calculations in three value look up tables representing minimum, average, and maximum times of event responses.

Latest time and range calculations were performed by STLG by working backward along the flight path, and starting with the last possible point of ground target intercept. Events were calculated in this fashion until the latest time of possible detection was derived. An example of each of the respective types of STLG output tables is provided in Tables 11 and 12.

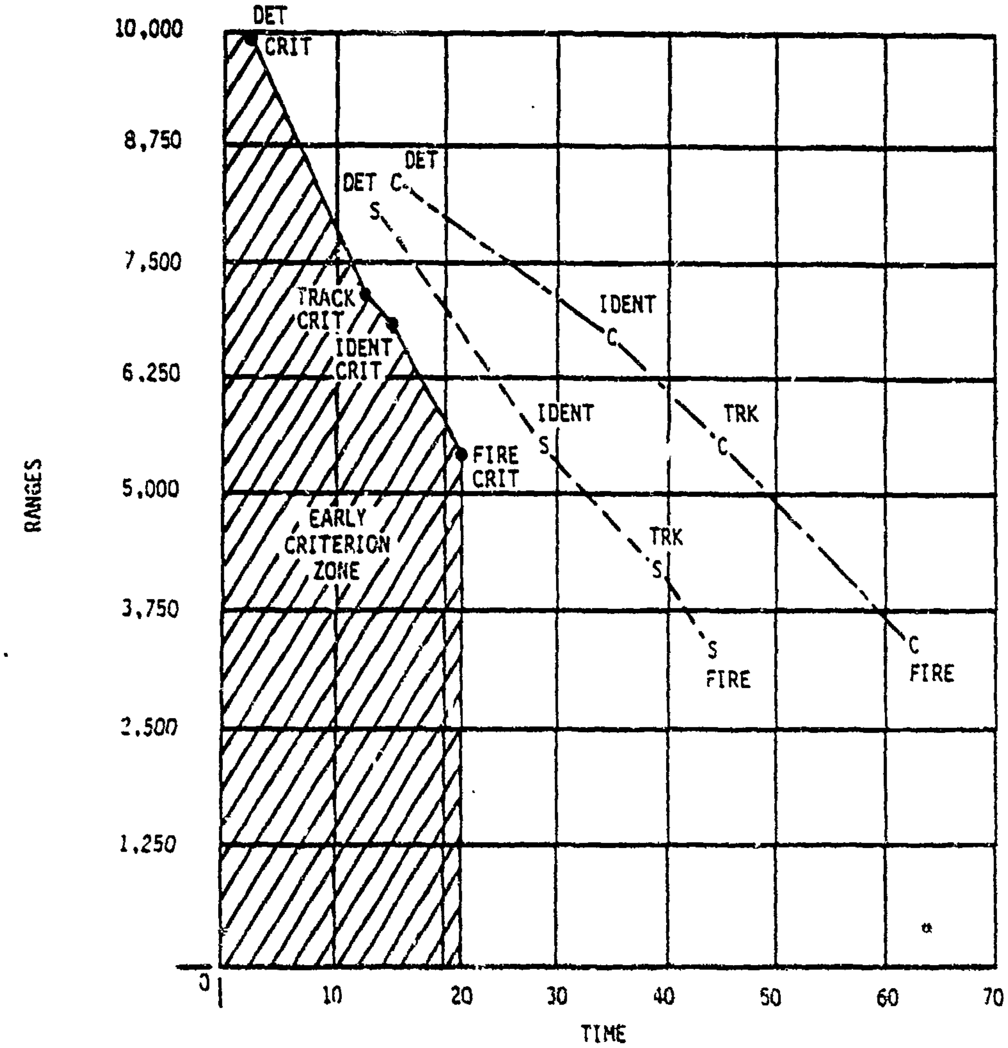
Figure 9 shows a plot of engagement event times and ranges for the Stinger and Improved Chaparral experimental test data bases. The shaded region on the left side of the plot represents the earliest time and range boundaries established using STLG. Latest time and range boundaries are not shown as they far exceed the actual maximum time values plotted.

Not even one experimentally-obtained event time or range exceeded earliest or latest time or range criteria. Thus, RADES fell within minimum fidelity tolerance limits. The detection, identification, track/lock-on, and fire events for each weapon were substantially later than the earliest times and substantially sooner than the latest times produced by STLG. The identification friend or foe (IFF) interrogation event was not plotted. IFF tended to occur both before and after detection in a seemingly random pattern possibly relating to crew training history.

Table 11

Expected Event Times

Critical Events	Early Times	Late Times
Available	0.00	81.00
Detected	0.25	81.25
Interrogated	-----	-----
Locked-On To	17.11	81.25
Identified	17.11	81.25
Fired-On	26.95	81.25
Break-Off	36.70	93.51



C ——— I-CHAPARRAL CREWS

S — — ·· — STINGER TEAMS

////// EARLY TIME & RANGE CRITERIA CALCULATED BY STLG PROGRAM.

NOTE: LATE TIME CRITERIA ARE GREATER THAN OBSERVED TIMES AND HAVE NEGATIVE RANGES. ALL RADES OBSERVED EVENTS OCCURRED EARLIER THAN LATE CRITERIA AND HAD POSITIVE RANGES.

FIGURE 9. COMPARISON OF OBSERVED RADES ENGAGEMENT TIMES AND RANGES WITH MINIMUM, PREDICTED, MAN IN-THE-LOOP ESTIMATES

Table 12

Human Factors Inclusive Expected Event Times

	EARLY TIMES			LATE TIMES		
Critical Events	Avg	Min	Max	Avg	Min	Max
Available	0.00	0.00	0.00	77.00	78.00	76.00
Detected	1.50	0.91	2.09	78.50	78.91	78.09
Interrogated	-----	-----	-----	-----	-----	-----
Locked-On To	17.44	17.45	17.42	79.74	80.20	79.37
Identified	18.74	18.51	18.46	81.09	81.26	80.91
Fired-On	27.40	27.37	27.37	81.50	81.67	81.32
Break-Off	33.05	37.57	38.26	94.74	94.62	94.82

COMPARISONS WITH PRIOR TEST RESULTS

Prior tests provide the primary validation criteria for this experimental test of RADES validity. Sources emphasized were field test results for the Stinger and I-Chaparral weapon systems, the Helicopter Acquisition Test (CDEC, 1978), and the Wright (1966) ground observer study.

Emphasis was placed on field test results, since these tests tended to represent the evaluations associated with system acquisition decisions. However, due to the secure nature of these sources, and the highly varied nature of their designs and treatments, discussions must be limited and inferences constrained. This situation was improved in the case of unclassified references. The Wright (1966) study was similar in design and relatively complete among air defense sources as an investigation of detection and identification under the condition of visual aiding and flight path offset effects. Thus, for detection and recognition issues, the Wright study was used more extensively to assess the validity of RADES results.

Comparisons between RADES and other results were performed using the _t_-test procedure. Independent samples _t_-tests (pooled variances) were performed whenever both sets of results provided the number of cases and standard deviations, enabling the assumption that variances may not necessarily be equal between the two groups. When the variance was unknown for the comparison sample, the comparison sample was treated as the population, and

its variance was estimated from the RADES sample. This technique assumes homogeneity of variance between the RADES sample and the hypothesized population.

Stinger OT II (Lott, 1977) versus RADES

The Stinger OT II (Lott, 1977), conducted by OTEA, has a limited similarity to RADES. The test conditions were somewhat different from those of RADES; for example, target availability for detection was derived differently. The Stinger OT II test is of major interest because it reports event times. Since fixed wing times for RADES were irrelevant, because of the flight path patterns, only rotary wing comparisons with the OT II data were possible. Further, since the event times were based on different scenario start times, only time intervals between events were comparable.

The OTEA test used experimental manipulations of aiding, early warning and type of aircraft, and compared performance of Redeye and Stinger teams (six teams per weapon), in clear sky, daylight conditions. During the non-fire exercise, subjects were exposed to simulated hostile and actual friendly fixed and rotary wing aircraft. The timed event of target identification minus target detection, in the aided recognition group, for rotary wing targets only, was the only result that could be directly compared with RADES.

The helicopters used in the OTEA study were the AH1G, CH47, OH58, and UH1H. Helicopter targets in the OTEA study either popped-up or performed an ingress maneuver. Data from OTEA rotary wing target stimuli were pooled across the two weapon groups (Redeye and Stinger) to obtain a population parameter estimate of mean time between target detection and recognition.

It was predicted that this duration would be equivalent to that obtained during RADES validation. Table 13 presents the *t*-test comparison between OTEA and RADES. The result of no-significant differences adds support to the suggestion of validity of RADES simulations.

Table 13

Stinger OT II and RADES *t*-test Comparisons

	I-Chaparral			Stinger		
Event	*t*	df	2-Tailed Probability	*t*	df	2-Tailed Probability
Time from Detection to Identification	0.74	7	$p > .10$	0.76	27	$p > .10$

<u>Helicopter Acquisition Test (1978) versus RADES</u>

CDEC (1978) conducted a Helicopter Acquisition Test (HAT) to assess the effects of cueing, terrain background, and target range on detection and recognition performance. This test is comparable to RADES with respect to the sky background and cueing aspects. The targets used in the HAT study were the OH58 and AH1G. RADES helicopters included the AH1G (Cobra) and the MI-24 (Hind-D). There is some degree of difference between the size of the OH58 used in the HAT study and the MI-24, used with RADES. These differences were reduced by collapsing the HAT data across all distances (ranges) for comparison with RADES. Event times were captured in the HAT test using a reference time from line-of-sight (LOS) to calculate subsequent event times. RADES helicopter event times were computed as a function of helicopter raise time; however, by allowing three seconds for the RADES target to reach LOS, the RADES times can be compared to those times generated by the HAT study.

Using the event times obtained from the HAT experiment (plus a constant of three seconds to account for the average time it took for RADES targets to reach LOS) as the population parameter estimates, *t*-tests were performed to compare RADES sample event times (assuming equal variances). Table 14 presents the results of these comparisons using estimated population parameters for time of detection as 9.5 seconds (6.5 + 3), time of identification as 19.5 seconds (16.5 + 3), and time of identification minus time of detection as 10 seconds (HAT data were extrapolated from figures). RADES times were not significantly different from the HAT times for both Stinger and I-Chaparral.

Table 14

Comparison of Rotary Wing Event Times Between the Helicopter Acquisition Test versus I-Chaparral and Stinger From RADES Validation

	I-Chaparral			Stinger		
Event	$\underline{t}$	df	2-Tailed Probability	$\underline{t}$	df	2-Tailed Probability
Time at Detection	2.24	8	$p < .10$	1.12	27	$p > .10$
Time at ID	1.50	7	$p > .10$	0.35	30	$p > .10$
Time at Detection minus Time at ID	0.87	7	$p > .10$	1.79	27	$p < .10$

<u>Stinger-Post OT II (Tillapaugh & Smith, 1983) versus RADES</u>

In 1983, another OTEA test was conducted using the Stinger weapon system. During this test, the basic Stinger was compared to the Stinger-Post configuration using experimental conditions of benign versus infrared countermeasures, type of target background, aircraft offset (0,1,2 and 4 kilometers), and a flare-drop condition. This OTEA test presented fixed wing sorties of two aircraft per run, during clear sky, daylight conditions at the same desert environment used during RADES validation. Four Stinger teams (two for each weapon configuration) were presented fixed and rotary wing fullscale targets. The tracking phase of the OTEA experiment was comparable to the RADES Validation experiment. The sky background data for the fixed wing (A-10 and A-7) runs were pooled across the two weapon systems. The A-10 and A-7 aircraft runs were chosen since these aircraft would represent a similar visual angle at 1:7 scale as the RADES fixed wing targets.

Since the OTEA study presented two aircraft per sortie and had flares dropping from the targets at regular intervals, it was expected that the detection event would not be comparable with that of RADES. Two aircraft dropping flares would be easier to locate than one not dropping flares. However, it was anticipated that identification event ranges would be comparable between the tests for those offsets of about one kilometer, since the recognition event would depend on the ability to discriminate target features at a given aspect angle.

Table 15 presents the comparison of results from RADES Stinger and I-Chaparral samples with those obtained by OTEA on the Stinger weapon. Using OTEA results as population parameters, *t*-tests were conducted to determine if events were different between the studies. As was predicted, the detection ranges were significantly different but the identification ranges were not. Interestingly, the ranges for Stinger superelevation, and for I-Chaparral events of IFF and Fire were also not significantly different from those obtained by OTEA.

Table 15

Fixed Wing Event Range Comparisons Between Stinger-Post OT II versus I-Chaparral and Stinger During RADES Validation

	I-Chaparral			Stinger		
Event	*t*	df	2-Tailed Probability	*t*	df	2-Tailed Probability
Range at Detection	3.70	13	$p < .01$	2.28	22	$p < .05$
Range at Interrogation	2.77	3	$p < .10$	3.50	16	$p < .01$
Range at ID	0.89	12	$p > .10$	0.62	20	$p > .10$
Range at Superelevation	----	--	-------	2.07	15	$p < .10$
Range at Fire	0.68	12	$p > .10$	2.40	20	$p < .05$

Chaparral DT/OT I (Clark, 1975) versus RADES

In 1975, OTEA conducted a test of the Improved Chaparral (I-Chaparral) weapon system. This test was conducted in phases, one of which was comparable to the RADES validation test. The DT/OT I phase of the OTEA test was conducted in the same desert environment as RADES tests. This test measured gunner performance in simulated tracking and engagement exercises using fullscale aircraft targets. The OTEA test varied such aspects as system configuration (use of IFF and TAA target acquisition devices), benign versus infrared countermeasures, weapon control status (free or tight), and visibility. Three fire units, placed side-by-side, were presented one aircraft per run during clear weather, daylight conditions.

While the OTEA experimental conditions were not identical to those of RADES, some of them were similar. The pooled results from OTEA (across weapons control status and across I-Chaparral units) were used to compare with RADES engagement results. During the OTEA test, targets were flown along a straight and level path directly towards the weapon positions. Since RADES target presentations varied in offset, it was assumed that the two studies would differ in aircraft identification performance, but would be similar in target detection ranges. It was assumed that the visual angle subtended by the target at detection would be similar, but during identification the discrimination task would differ between the two tests, because of the difference in the distance at which enough target features would be visible to enable discrimination. Using the OTEA event ranges as valid population parameter estimates, t-tests were performed based on the assumption of homogeneity of variances. The predictions that identification ranges would differ, but visual detection ranges would not, were supported.

Table 16 presents the results of t-test comparisons of fixed wing target engagements between I-Chaparral (OTEA, 1975) and RADES Validation results for I-Chaparral and Stinger. The RADES results were not significantly different from those of OTEA for detection, but were different for identification. Further, the range at weapon fire was not different between the OTEA and RADES I-Chaparral tests. Additionally, the RADES I-Chaparral sample was not significantly different from the OTEA sample with respect to percent of correct fixed wing identifications.

Table 16

Fixed Wing Event Range Comparisons Between I-Chaparral DT/OT I versus I-Chaparral and Stinger During RADES Validation

	I-Chaparral			Stinger		
Event	t	df	2-Tailed Probability	t	df	2-Tailed Probability
Range of Detection	1.1	13	$p > .10$	0.17	22	$p > .10$
Range of ID	4.25	12	$p < .01$	4.53	20	$p < .01$
Range of Fire	0.92	12	$p > .10$	3.03	20	$p < .01$
% Correct ID	0.49	14	$p > .10$	2.94	22	$p < .01$

Chaparral and Redeye TSEA (TRASANA, 1981) Correct IDs versus RADES Correct IDs

RADES aircraft identification data can be favorably compared to that reported by TRASANA (1981) for Chaparral crews. In this research, 450 Chaparral crewmembers, representing 12 CONUS (Continental U.S.) units, had their visual identification skills tested using the Goar kit slides. These slides present both fixed wing and rotary wing aircraft in various orientations. In RADES, troops are required to make a "hostile" or "friendly" identification response. The TRASANA troops were asked to make a specific identification by either alpha-numeric designator (e.g., MIG-27) or the NATO designation (e.g., Flogger). Fortunately, the TRASANA data are presented in such a fashion that performance with the dichotomous response category (hostile or friendly) can be interpolated accurately. The TRASANA identification data were compared to the proportion of correct identifications that Chaparral crewmembers made during the RADES validation test. The results are shown in Table 17. (Note: The RADES data presented in Table 17 are subject to the same caveat as those presented earlier in Table 10.)

Table 17

TRASANA (1981) versus RADES Chaparral Crewmembers: Mean Percent Correct Identifications

TRASANA (1981)	RADES (fixed wing and rotary wing combined)*
82	83

* Note: Caveat at bottom of Table 10 applies here also.

The TRASANA results ranged from a unit low of 71 percent correct to a unit high of 92 percent correct, with a standard deviation across the units of 7 percent. Such similarities in measured performance as these (82% vs 83%) contribute to the interpretation that RADES is an empirically valid simulator.

Wright (1966) versus RADES: Comparison of Detection Ranges

Wright conducted visual aircraft detection and recognition tests at Fort Bliss, Texas (Dona Ana Range) in 1966 under environmental conditions similar to those found at the RADES facility. Meteorological visibility may have been greater than is currently found in the area, but other conditions were almost identical. Three dependent measures were obtained: detection, tentative identification, and positive identification. Wright included the use of binoculars (6 x 30) to measure the effect of aiding in detection and recognition performance. For RADES validation purposes, only the unaided detection and aided recognition are of interest. One other independent variable used by Wright was observer offset. Observer offset is defined as the closest distance the aircraft comes to the observer. Offset is measured along a perpendicular line drawn between the observer's position and the flight path of the aircraft. Wright used three observer positions with nine observers at each site. (See Figure 10). The aircraft were flown along ten flight paths, all of which were to converge over observer Site A. All observers at Site A essentially had a head-on view of the targets, thus the offset for this group was zero meters. Site B was located about 1000 meters from Site A and Site C 2000 meters. Table 18 presents the approximate offsets from each flight path for Sites B and C.

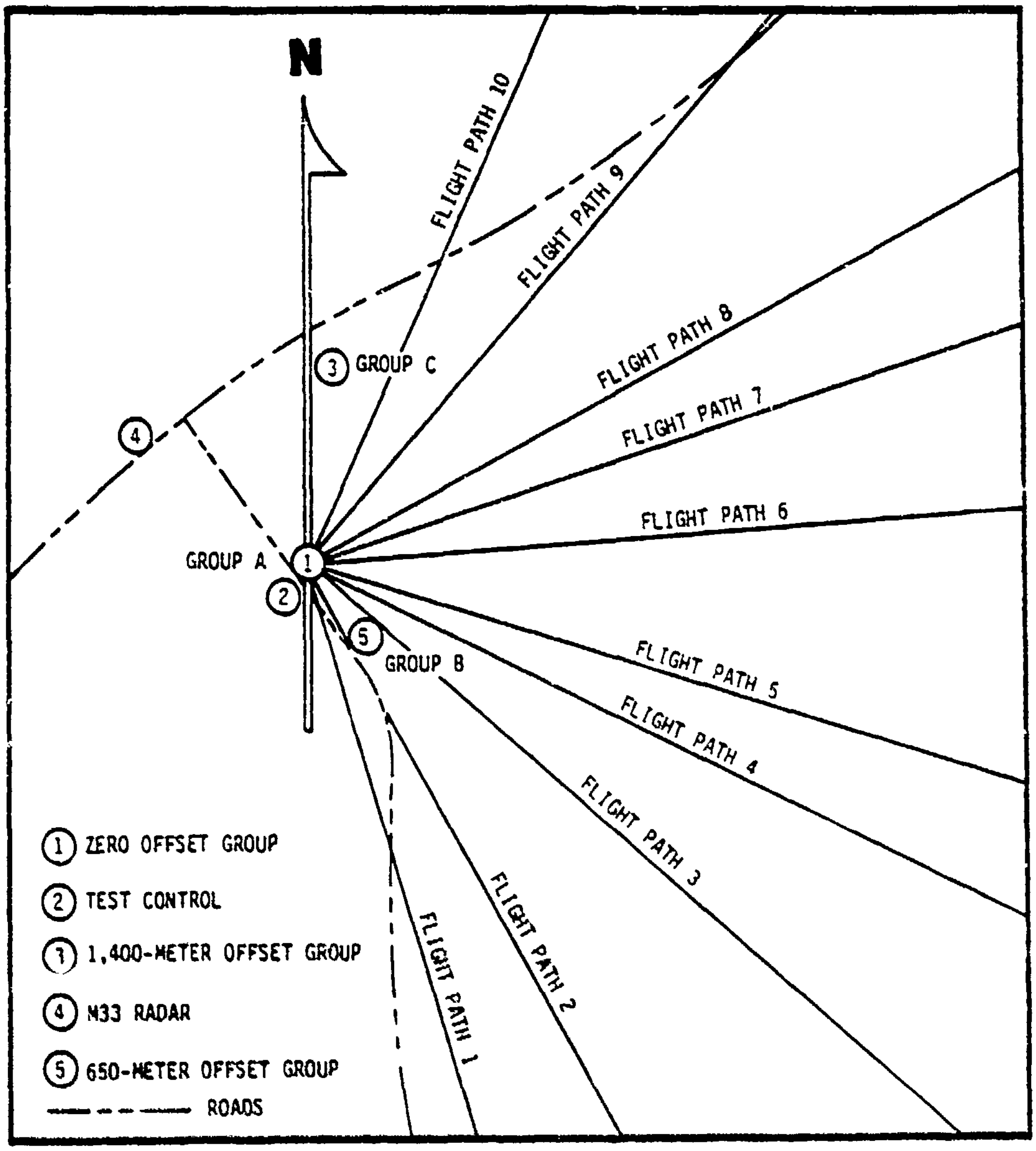


FIGURE 10. ANGULAR OFFSET SITES AND FLIGHT PATH USED BY WRIGHT (1966)

Table 18

Offset Range in Meters During the Wright Study

	Flight Paths									
	1	2	3	4	5	6	7	8	9	10
Site B	400	150	150	400	600	800	950	1000	1000	900
Site C	900	1300	1700	1900	1900	1900	1700	1550	1050	600

Wright assigned a nominal offset range to each observer site, which was approximately the average of the offset ranges in Table 18. Site A offset was 0, Site B 650 meters and Site C 1400 meters. In the RADES validation study, there was an attempt to hold the offset range at a constant 1000 meters (fullscale) but it actually varied about a mean of 1040 meters. Since offset distance influences detection and identification ranges, Wright's Site B data were selected for RADES validation purposes. Both studies used alerting and early warning cues.

Wright used actual U.S. Air Force jet aircraft that on the surface appeared to be quite different from the RADES targets. Wright used the F-4C, F-100, and T-33 fixed wing full scale aircraft, as compared to the one-seventh scale F-16 and MIG-27 aerial targets in the RADES validation test. However, the relative size of the aircraft, after accounting for scale, would be similar in that they would subtend, on the average, approximately the same visual angle.

Normally the head-on (0 meters offset) view of an aircraft presents the smallest visual image of the aircraft. As the offset distance increases, more of the fuselage can be seen and a larger visual image is presented (at or near threshold distances). The F-100, F-16, and MIG-27 all present a rather conventional jet aircraft image, whereas the F-4C has dark exhaust smoke trailing behind it, which in the head-on view is very dense and enlarges the visual image of the aircraft. In the side view, the smoke has less of an impact on the presented image. However, as the view changes from head-on to the full side view the image projected by the aircraft itself grows larger. Image wise, the F-4C is a relatively large aircraft and the smoke adds tremendously to the image size. This fact shows up in the detection ranges that have been reported in studies using this aircraft.

The T-33 was anomalous in that it had fuel tanks mounted on the wing tips. The head-on view of the T-33 created a perceptual image of three large dots at visual threshold, which people tend to connect in their processing of the visual information. In effect, this creates a larger image than the traditional aircraft image would present in the head-on view. In the side view, the wing's tanks blend in with the fuselage and present no significant cues for detection or for recognition at beyond feature discrimination threshold.

Normally, in the zero meters offset position, detection and recognition ranges would be expected to be relatively short and it would be expected that as offset distances increase to a point, detection ranges would increase. Therefore, for RADES validation purposes, criterion comparisons were made of data collected under the most similar conditions possible. This leads to the selection of Wright's data for Site B (650 meter offset) observers as the most logical choice. The RADES study used visual aiding for the recognition response but not for the detection response. Therefore, data for the unaided detection and aided recognition trials were used for the validation comparison.

Table 19 presents t-test results for the comparison of RADES results with Wright's results. Since data were collected for two groups of subjects (Chaparral crews and Stinger teams) in the RADES study, two detection means are compared to the Wright data. Wright did not report the standard deviations in his report, so his means were treated as estimates of the population parameter and homogeneity of variance was assumed.

Table 19

Comparison of RADES and Wright's Detection Ranges (KM)

Test Group	t	df	2-Tailed Probability
I-Chaparral	2.20	13	$p < .05$; $p > .01$
Stinger	2.55	22	$p < .05$; $p > .01$

The mean detection range of 9.4 kilometers reported by Wright was significantly greater than that of the Stinger teams (8.1 KM) or the Chaparral crews (8.5 KM) tested in RADES. This failure by RADES to duplicate the detection range reported by Wright was disappointing, since the two studies were similar in many ways. Perhaps this greater detection range was caused by

the greater smoke trail produced by the fullscale aircraft. RADES aircraft do not leave a smoke trail. Fullscale jets sometimes do. The F-4C used by Wright produced a very noticeable smoke trail (Wright, p. 11). This smoke contributed to a far greater detection range overall for the F-4C (14.4 KM) than for the F-100 (10 KM), which smoked less, or the T-33 (7.5 KM), which did not smoke (Wright, p. 16). It may be instructive that the overall detection range of the nonsmoking T-33 was closest to those ranges found in RADES.

Wright (1966) versus RADES: Comparison of Recognition Ranges

At the time Wright (1966) conducted his field study, the Forward Area Air Defense engagement cycle was not yet formalized, so he chose two forms of aircraft recognition (identification) responses. He reasoned that FAAD personnel would attempt to identify the aircraft as early as possible (farthest range possible), but might change their minds when more information was available. He instructed his subjects to respond as soon as possible, after they detected a target, with an identification announcement (which was recorded by a test observer assigned to each subject). He called this "tentative recognition". This was a subjectively better than chance guess, but still an uncertain response (i.e., "I think it might be an F-100"). In the RADES event set this tentative recognition response equated to a crew member's first announcement of a target's identity (friend, foe, unknown, or model of aircraft).

Wright's positive recognition response was made when the observer was subjectively certain of a correct identification (i.e., "I'm sure it's an F-100"). Today in the FAAD engagement event cycle, final identification is the responsibility of the crew leader. The crew leader can change the identification response at any time up to the time he gives the order to fire or break-off engagement. Therefore, in the RADES validation test, the positive identification response relates primarily to the fire event. Thus, these data were used to compare with the positive recognition event in Wright's study.

The data from the Wright study used for RADES validation comparisons were collected from the observer group at Site B (650 meter offset) and for the trials where binoculars were used for recognition but not for detection of the targets. As with the detection comparison, it would appear that the data from the aided detection/aided recognition trials would not be useable for the validation comparison, because there was a strong indication that there was a significant interaction, or some form of confounding, occurring between the aided detection and the aided recognition trials. When comparing the recognition data across the treatment conditions of aided versus unaided visual recognition, it appears that Wright's subjects were able to gather some recognition cues during the detection event when they were using binoculars for detection. This advantage did not

exist in the RADES study. Table 20 presents a comparison of Wright's recognition means collapsed across offsets (Wright found no significant effect of offset on recognition performance in his analysis of variance).

Table 20

Mean Recognition Ranges (KM) as a Function of Visual Aiding

	Tentative Recognition	Positive Recognition
Unaided/Unaided	5.4	2.5
Unaided/Aided	6.8	4.2
Aided/Aided	7.4	4.5

The comparison of the RADES data for the most comparable conditions from the Wright study (650 meter offset, under the unaided detection and aided recognition condition) revealed non-significance for both the Chaparral and Stinger groups. Table 21 presents the comparisons between Wright's tentative recognition and RADES recognition events. Table 21 also presents comparisons between Wright's positive recognition and RADES fire events.

The conclusion to be drawn from the results of the *t*-tests shown in Table 21 is that there is relatively strong support for establishing the validity of RADES as a measurement testbed for the study of the recognition event in the FAAD engagement cycle.

Table 21

Comparison of Wright's and RADES Recognition Ranges

	Tentative		Positive	
Test Group	*t*	df	*t*	df
I-Chaparral	0.99	12	0.51	12
Stinger	0.47	20	0.71	20

All *t*-values are non-significant at the .05 level.

RADES CONSISTENCY

Results of RADES tests conducted subsequent to the Validation study have further demonstrated the validity of RADES in obtaining representative data on FAAD engagements. Although a formal report of RADES Baseline test results has not been released, the data have been validated against those obtained from field tests and human performance studies (e.g., Helicopter Acquisition Test, 1978; Stinger-Post OT II, 1983; I-Chaparral DT/OT, 1975; Wright, 1966).

Further, RADES Validation results have been replicated in RADES Baseline studies, which suggests that RADES has consistency (reliability) over time. For example, the I-Chaparral Baseline test was similar to the Validation test for the rotary wing conditions, and yielded similar results. Table 22 presents the comparison of I-Chaparral rotary wing event times in the Validation and Baseline tests, using an independent samples *t*-test with pooled variance estimates. Since the helicopter availability times can vary as a function of stand type, stand placement, and weapon placement, raw event times were not compared. Only comparisons of processed event times are reported in Table 22. No comparisons were statistically significant at the .05 level. That is, all events subsequent to detection yielded comparable results. Also, the percent correct identfications for helicopters was 88% in the I-Chaparral Baseline test and was 90% for I-Chaparral in the Validation test.

Table 22

I-Chaparral Validation versus I-Chaparral Baseline: Rotary Wing Event Time Comparisons for the First Pop-up Target

Event	t	df	2-Tailed Probability
Time at Interrogation Minus Detect	1.85	75	$p < .10$
Time at Identification Minus Detect	0.76	78	$p > .10$
Time at Lock-on Minus Detect	1.61	52	$p > .10$
Time at Fire Minus Detect	0.88	40	$p > .10$
Time at Break-off Minus Detect	1.44	14	$p > .10$

The RADES Stinger Baseline test was also similar to the Validation test. Stinger Baseline fixed wing and rotary wing scenarios for the sky background conditions were compared to those of the Stinger Validation experiment. Table 23 shows the comparison for processed rotary wing event time intervals and Table 24 shows the comparisons for fixed wing event ranges. Generally, the Stinger Baseline results were comparable to those of Stinger Validation. There were no significant differences in the rotary wing event time intervals of interrogation, lock-on, identification, and break-off. There were significant differences in the times from detect to superelevate and to fire, with the Stinger Baseline times being shorter. Presumably, this was due to the greater training and experience of the Baseline gunners. Table 24 shows that there were no significant differences between the Validation and Baseline fixed wing event ranges at detection, lock-on, superelevation, and fire. There were significant differences in range at interrogation and identification, with the Baseline teams interrogating the aircraft at greater ranges but identifying them at lesser ranges.

Table 23

Stinger Validation versus Stinger Baseline: Rotary Wing Event Time Comparisons for the First Pop-up Target

Event	$\underline{t}$	df	2-Tailed Probability
Time at Interrogation Minus Detect	0.61	67	$p > .10$
Time at Lock-on Minus Detect	1.84	65	$p < .10$
Time at Identification Minus Detect	0.65	98	$p > .10$
Time at Superelevation Minus Detect	3.66	63	$p < .01$
Time at Fire Minus Detect	2.72	62	$p < .01$
Time at Break-Off Minus Detect	0.44	33	$p > .10$

Table 24

Stinger Validation versus Stinger Baseline: Fixed Wing Event Range Comparisons

Event	$\underline{t}$	df	2-Tailed Probability
Range at Detection	0.05	69	$p > .10$
Range at Interrogation	2.35	51	$p < .05$
Range at Lock-on	1.06	54	$p > .10$
Range at Identification	3.88	67	$p < .01$
Range at Superelevation	0.28	50	$p > .10$
Range at Fire	0.05	55	$p > .10$

LESSONS LEARNED FROM VALIDATION TESTING

There were a multitude of lessons learned from the Validation test. These resulted in a number of modifications made to RADES in FY84 and FY85 in an effort to improve its realism, utility, and validity. First, RADES was moved to another location at Condron Field. This new location allows for better masking of the fixed and rotary wing targets prior to the start of a trial. In addition, it provides the option of either a mountain or a sky background.

Modifications were also made at the RADES weapon position. In order to prevent participants from employing audible cues as an aid to fixed wing detection, battle noise is now played from all-weather speakers at the weapon position during engagement exercises. This battle noise serves not only to mask auditory detection cues, but it also masks radio messages between RADES Control and the ARI Field Test Representative. In addition, it serves to heighten the realism of the simulation. In addition, an azimuth and elevation transducer was purchased for use with Redeye and Stinger to assure precise determination and measurement of where the gunner is aiming. This sensor is capable of simultaneously measuring azimuth and elevation to withhin one degree of arc.

Most of the modifications were to the subscale targets. RADES now employs six helicopter stands, with plans for acquiring more. A new type of helicopter stand was purchased, which is lighter and more reliable. All six stands are of this new type. (The three older stands were salvaged and served other FAAD needs.) These six rotary wing targets were moved a greater distance from the weapon position, in order to more realistically test the troops' detection and identification abilities. Current plans call for all rotary wing targets to occupy a fullscale range of from two to five kilometers. Finally, an increased number of friendly and hostile rotary wing types have been purchased.

The fixed wing targets have also undergone numerous modifications. First, more powerful radio frequency transmitters were purchased. Also, a third pilot has been added to the mission scenario. Together, these modifications will allow the fixed wing targets to fly to a greater range and thereby more accurately test troops' detection and identification abilities. In addition, a pneumatic catapult launcher was purchased. This launcher is entirely self-contained, ruggedized, and capable of launching planes at 40 mph. It is light, easily towed, and can be positioned by hand to face into the wind. It allows RADES much greater flexibility and dependability in the launching of aircraft. Next, new aircraft were purchased. The planes are constructed of fiberglass, making them both lighter and stronger. Further, more model types of fixed wing aircraft were purchased. This increase in the size of the target squadron allows RADES to portray the identification problem more realistically.

CONCLUSIONS

The purpose of this report has been to describe the research performed during the spring of 1984 to validate the RADES simulation. Validation of the RADES facility proceeded from two rather different perspectives, which can be considered internal validity and external validity. Demonstrating internal validity involved developing performance limits for the engagement events from a model (the STLG) which took as its input the physical electromechanical limits imposed by each weapon system, human reaction time parameters as published in the human factors literature, and the specific flight path of the fixed wing aircraft. Minimum, maximum, and mean engagement event times and distances were derived from this model for each critical step in the engagement sequence, for each flight path, and for each weapon system. These theoretical limits were used as criteria against which RADES validation test data were compared. Obtained engagement event times and distances, for both weapon systems, were within the calculated event tolerance limits. Thus, performance data obtained during the RADES simulation did not exceed limits predicted from known limitations of the weapon system plus reaction time plus flight path combination. Internal validity was also demonstrated in terms of consistency over time. RADES tests conducted subsequent to this Validation study have yielded similar results to those reported here.

External validity refers to comparing the observed performance obtained in RADES with performance obtained in other relevant studies available in the literature. It was demonstrated that RADES's measures of engagement event times, engagement event distances, and identification accuracies were consistent with similar measures for fullscale aircraft found in the literature. Performance obtained during the RADES subscale simulation was consistent with performance obtained during earlier fullscale field exercises. Thus, on the basis of both internal and external criteria, it is concluded that RADES is a valid means of simulating the engagement process.

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